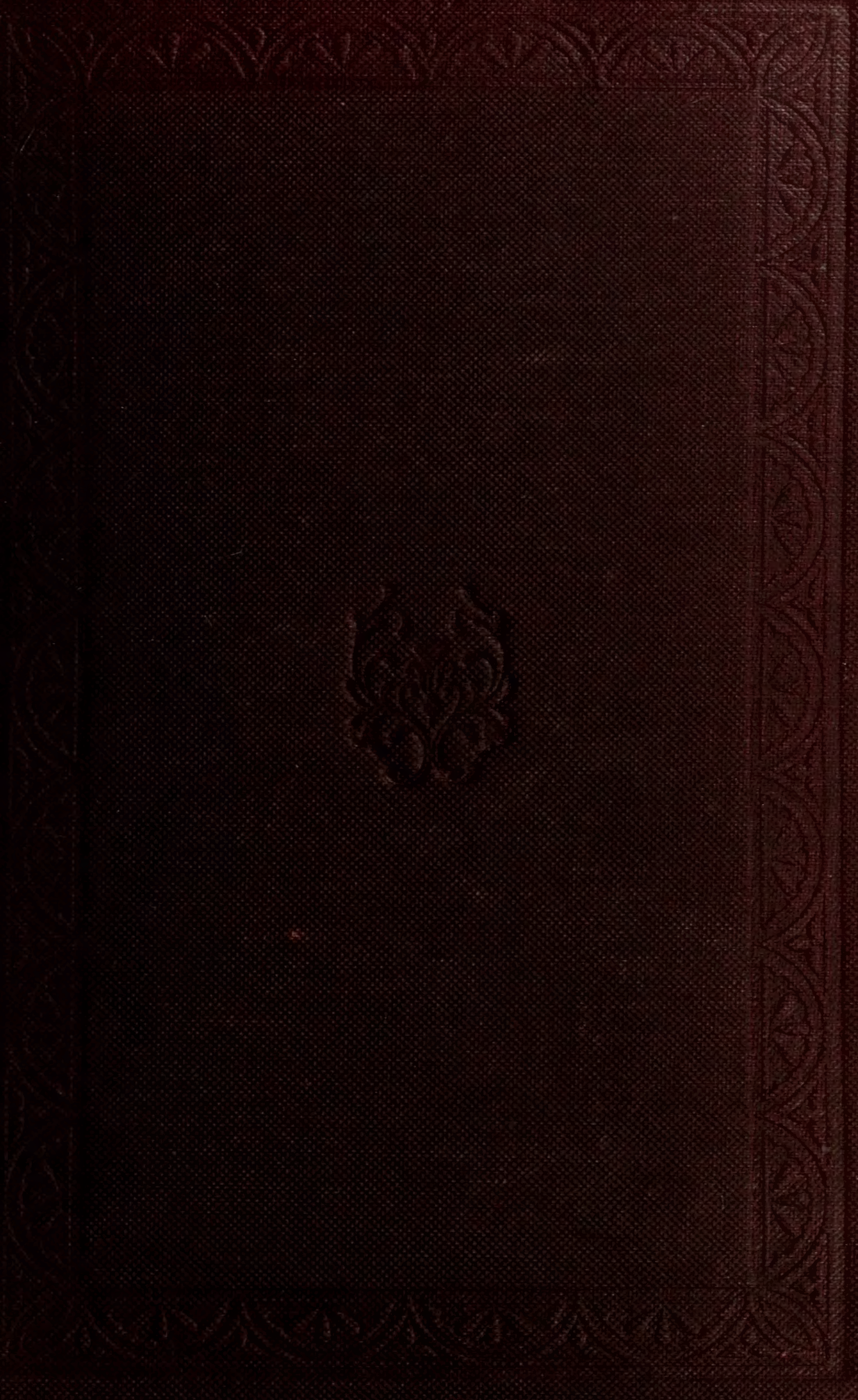

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THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1921.
JANUARY–MAY.

VOL. I.

165759
7/10/21

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CONTENTS.

1921.
January–May

PAGE
List of Past-Presidents and Past-Vice-Presidents iv
List of Officers v
Annual Report of the Council for 1920 1
"A small Ball-Hardness Testing-Machine"; by H. Moore, O.B.E. (Plates 1–2) 51

Proceedings, January Meeting:—

Decease of Walter Pitt 63
Council Retiring and Nomination Lists 63
Election of Members, etc., and Transferences 65
"Mechanical Loading of Ships"; by H. J. Smith (Plates 3–10) . 67
"Mechanical Qualities of Eyebolts"; by R. T. Rolfe (Plate 11) . 177
"Screw-Thread Gauges"; by T. F. Davey 191
Unveiling and Dedication of War Memorial (Plate 12) 197

Proceedings, 74th Annual General Meeting, 18th February:— .

Election of Members, etc., and Transferences 201
Discussion and adoption of Annual Report 203
Benevolent Fund 209
Presentation of Prizes 210
Election of Council 210
Appointment of Auditor 213
Graduates' Lecture: "Generation of Steam"; by Sir John Dewrance K.B.E. 215
"Standardization of Testing Welds"; by F. M. Farmer (Plates 13–15) . 225
Joint Meeting with Society of Chemical Industry, 4th March:— . 289
"Purification of Boiler Feed-Water"; by P. Kestner 291

Proceedings, March Meeting:—

Election of Members, etc., and Transferences. 361
"Contact Pressures and Stresses"; by E. G. Coker, K. C. Chakko, and M. S. Ahmed (Plates 16–17) 365

PROCEEDINGS, APRIL MEETING :— PAGE
Election of Members, etc., and Transferences 469
"Limit Gauging"; by Sir R. T. Glazebrook, K.C.B. . . . 473
PROCEEDINGS, MAY MEETING :—
Election of Members, etc., and Transferences 531
Memoirs 535
Index to Proceedings 1921, January to May 553
PLATES 1–17.

The Institution of Mechanical Engineers.

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)
Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)
Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)
John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)
James Kennedy, 1860. (*Deceased* 1886.)
The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869. (*Deceased* 1900.)
Robert Napier, 1863–65. (*Deceased* 1876.)
John Ramsbottom, 1870–71. (*Deceased* 1897.)
Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75. (*Deceased* 1903.)
Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)
John Robinson, 1878–79. (*Deceased* 1902.)
Edward A. Cowper, 1880–81. (*Deceased* 1893.)
Percy G. B. Westmacott, 1882–83. (*Deceased* 1917.)
Sir Lowthian Bell, Bart., LL.D., F.R.S., 1884. (*Deceased* 1904.)
Jeremiah Head, 1885–86. (*Deceased* 1899.)
Sir Edward H. Carbutt, Bart., 1887–88. (*Deceased* 1905.)
Charles Cochrane, 1889. (*Deceased* 1898.)
Joseph Tomlinson, 1890–91. (*Deceased* 1894.)
Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)
Sir Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.
E. Windsor Richards, 1896–97.
Samuel Waite Johnson, 1898. (*Deceased* 1912.)
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., 1899–1900. (*Deceased* 1913.)
William H. Maw, LL.D., 1901–02.
J. Hartley Wickstead, 1903–04. (*Deceased* 1919.)
Edward P. Martin, 1905–06. (*Deceased* 1910.)
T. Hurry Riches, 1907–08. (*Deceased* 1911.)
Sir John A. F. Aspinall, M.Eng., 1909–10.
Edward B. Ellington, 1911–12. (*Deceased* 1914.)
Sir H. Frederick Donaldson, K.C.B., 1913–14. (*Deceased* 1916.)
W. Cawthorne Unwin, LL.D., F.R.S., 1915–16.
Michael Longridge, C.B.E., 1917–18.
Edward Hopkinson, D.Sc., M.P., 1919.

PAST-VICE-PRESIDENTS.

William H. Allen,	Bedford.
Henry Davey,	Ewell.
J. Rossiter Hoyle,	Sheffield.
Mark H. Robinson,	London.

The Institution of Mechanical Engineers.

OFFICERS.

1921.

PRESIDENT.

Captain H. Riall Sankey, C.B., C.B.E., R.E., ret.,	London.

PAST-PRESIDENTS.

Edward Hopkinson, D.Sc., M.P.,	Manchester.
Michael Longridge, C.B.E.,	London.
William H. Maw, LL.D.,	London.
W. Cawthorne Unwin, LL.D., F.R.S.,	London.

PAST-VICE-PRESIDENTS.

William H. Allen,	Bedford.
J. Rossiter Hoyle,	London.
Mark H. Robinson,	London.

VICE-PRESIDENTS.

Sir John Dewrance, K.B.E.,	London.
Sir Robert A. Hadfield, Bart., D.Sc., D.Met., F.R.S.,	Sheffield.
H. S. Hele-Shaw, LL.D., D.Sc., F.R.S.,	London.
Sir Gerard A. Muntz, Bart.,	Birmingham.
William H. Patchell,	London.
Sir Vincent L. Raven, K.B.E.,	Darlington.

MEMBERS OF COUNCIL.

Daniel Adamson,	Hyde.
Richard W. Allen, C.B.E.,	Bedford.
H. I. Brackenbury, C.B.E.,	Newcastle-on-Tyne.
Sir George J. Carter, K.B.E.,	Birkenhead.
Alan E. L. Chorlton, C.B.E.,	London.
Professor William E. Dalby, F.R.S.,	London.
Lieut.-Colonel A. E. Davidson, D.S.O., R.E.,	London.
Sir Henry Fowler, K.B.E.,	Derby.
Henry A. Ivatt,	Hayward's Heath.
Christopher W. James,	London.
L. A. Legros, O.B.E.,	London.
Frederick H. Livens,	Lincoln.
Donald B. Morison,	Hartlepool.
Loughnan St. L. Pendred,	London.
Ernest W. Petter,	London.
William Reavell,	Ipswich.
David E. Roberts,	Cardiff.
George R. Sharpley,	Lincoln.
Thomas E. Stanton, C.B.E., D.Sc., F.R.S.,	Teddington.
William Taylor, O.B.E.,	Leicester.
Richard Williamson,	Workington.

CHAIRMAN OF LOCAL BRANCHES.

North-Western Branch.—Charles Day.
Midland Branch.—E. C. R. Marks.
Yorkshire Branch.—Lieut.-Colonel E. Kitson Clark.

HON. TREASURER.	AUDITOR.
F. H. Norwood.	Raymond Crane, F.C.A.

SECRETARY.

Brig.-General Magnus Mowat, C.B.E.

ASST. SECRETARY (General).	ASST. SECRETARY (Technical)
H. T. Chapman.	J. E. Montgomrey.

The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, London, S.W. 1.
Telegraphic Address:—*Mech, Parl, London.* Telephone: *Victoria*, 4564.

The Institution of Mechanical Engineers.

PROCEEDINGS.

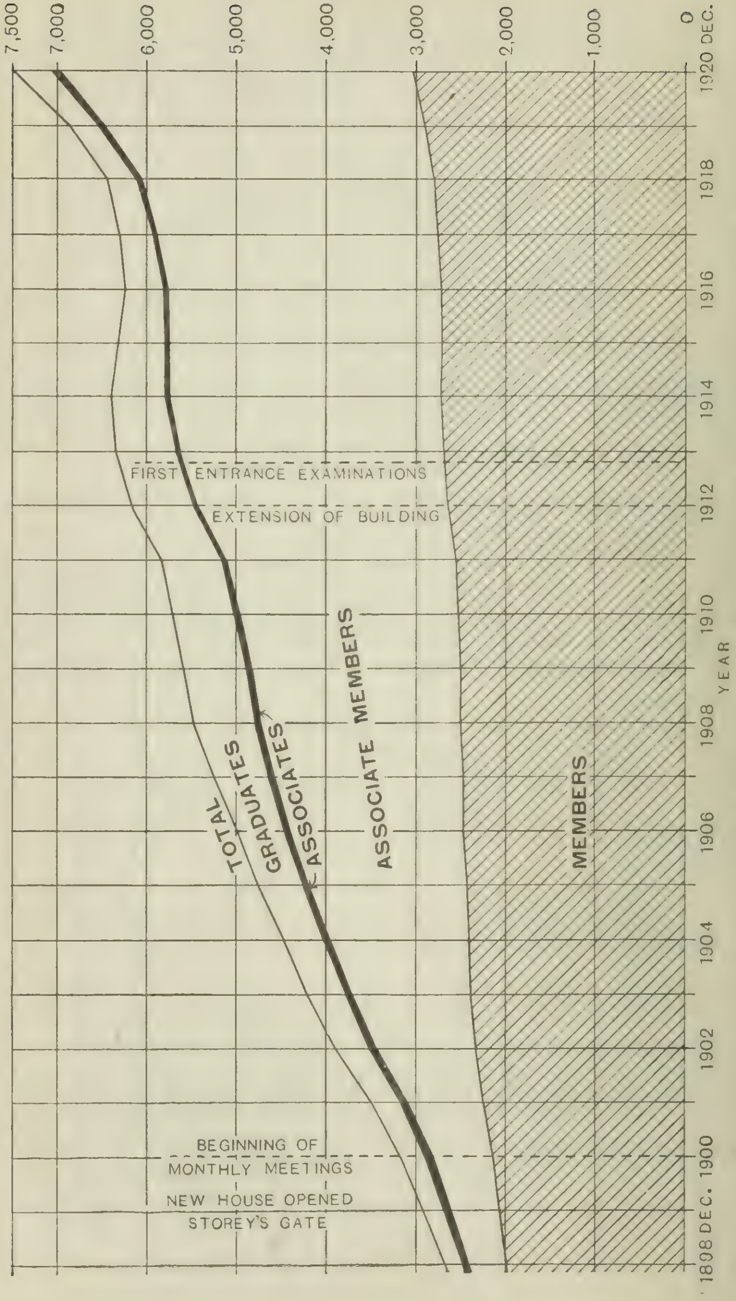
ANNUAL REPORT OF THE COUNCIL
FOR THE YEAR 1920.

The Council have pleasure in presenting to the members at the Seventy-fourth Annual General Meeting their Report of the progress and work of the Institution during the year.

The changes which have taken place in the roll during 1920 are shown in the subjoined tabulated statement:—

	Hon. M.	M.	A.M.	A.	G.	Totals.	
Totals at 31st December 1919	10	2,902	3,557	68	322		6,859
Elected	—	128	463	14	213		
Reinstated	—	4	16	—	—		
Transferred	—	56	—	—	—		
Total additions during 1920	—	188	479	14	213	894	
Deceased	—	43	20	1	2		
Resigned	—	10	20	2	5		
Erased	—	6	18	—	2		
Graduates elected Associate Members	—	—	—	—	25		
Graduates retired under By-law 3	—	—	—	—	38		
Elections voided	—	—	1	—	1		
Transferred	—	—	56	—	—		
Total deductions during 1920	—	59	115	3	73	250	
Net alterations during 1920	—	+129	+364	+11	+140		+644
Totals at 31st December 1920	10	3,031	3,921	79	462		7,503

DIAGRAM SHOWING GROWTH OF THE INSTITUTION FROM 1898 TO 1920.



(For the Curve from December 1847 to 1913, *see* Annual Report for 1914, January Proceedings 1915, page 16.)

His Majesty the King has conferred the following honours upon members :—

Baronetcies.—Sir A. Trevor Dawson; Colonel John R. Wright.

Order of the Bath.—Sir Richard T. Glazebrook, K.C.B., F.R.S. (*Hon. Life Member*); Lieut.-Colonel D. Paul, C.B., C.M.G., C.B.E., R.A.O.C.

Order of St. Michael and St. George.—Lieut.-Colonel H. N. Foster, C.M.G., C.B.E., R.A.S.C.; Brig.-General George Rollo, C.M.G., D.S.O.; Lieut.-Colonel C. F. Rundall, C.M.G., D.S.O., R.E.; Colonel H. E. Webb-Bowen, C.M.G., D.S.O., R.E.

Order of the Indian Empire.—Brig.-General Lord Montagu of Beaulieu, K.C.I.E., C.S.I.; Major Harold Berridge, C.I.E., O.B.E., R.E.; R. W. H. Marris, C.I.E.

Order of the British Empire.

Knight Grand Cross (*G.B.E.*).—Brig.-General Sir Alexander Gibb, C.B.

Knights Commander (*K.B.E.*).—Samuel H. E. Barraclough; The late H. S. B. Brindley; John Dewrance; Fred Lobnitz; Alfred Mansfield; J. E. Petavel; Captain F. W. Young, C.B.E.

Commanders (*C.B.E.*).—James E. Anderson; David Carnegie; C. C. Carpenter, D.Sc.; Wing Com. T. R. Cave-Browne-Cave; Professor J. D. Cormack, C.M.G., D.Sc.; Alexander Craig; A. L. C. Fell; M. S. Gibb; Maurice Graham; H. N. Gresley; N. G. Gwynne; George Hughes; Lieut.-Colonel P. H. Johnson, D.S.O.; W. J. Larke; James Le Masurier; Michael Longridge; Brig.-General Magnus Mowat; Lieut.-Colonel R. Oakes, R.E.; W. H. Prescott, M.P.; R. Whyte Reid; J. G. Robinson; A. C. Rogerson; A. J. C. Ross; Captain H. Riall Sankey, C.B., R.E.; A. C. Stamer; T. E. Stanton, D.Sc., F.R.S.; H. Travis.

Officers (*O.B.E.*).—W. C. Acfield; Percy R. Allen; Neale Andrews; Lieut.-Colonel N. M. Barron; Robert Blackburn; Thomas H. Brocklebank; J. W. Brooke, J.P.; R. P. Brousson; Major F. A. W. Brown; Robert A. Bruce; Francis Carnegie; H. Emory Chubb; G. E. Clarke; C. B. Collett; Thomas Cook; H. L. Critchley; Major B. J. Day, R.E.; J. B. Dumbell; Eng. Com. W. R. Fendick, R.N.; P. W. Fawcett; Peter Frank; C. W. L. Glaze; Major T. E. Goodeve, R.E. (*deceased*); O. S. Hall; J. J. Hanbury; Captain E. D. A. Herbert, R.G.A.; Benjamin Hick; L. B. Hogarth; Prof. A. R. Horne; Major E. J. Howard, R.A.F.; Major A. R. Layard, R.A.F.; Percy Leresche; Major J. C. M. Manley, R.F.A.; R. G. Nicol; Prof. John Orr; A. A. Remington; C. O. Ridley; L. B. Robinson; Major Leslie Roseveare; Major B. W. Shilson, R.A.S.C.; J. H. Smeddle; C. E. Stromeyer; Arthur Stubbs; R. A. Thom; Lieut.-Col. J. J. Thompson; W. A. C. Thorpe; R. P. Tod; Major G. L. Walton, R.E.; D. E. Wilson; G. W. Woolliscroft; Major A. J. Wright, I.O.M., R.A.O.C.

Members (*M.B.E.*).—Captain James Bacon, R.E.; Edward Birrell; W. G. Carter; E. W. Cash; L. Chatfeild Clarke; James Clayton; Major P. J. Cowan; H. J. Donkin; J. S. Ferguson; E. Hubert Field, M.C.; F. A. Fleming; P. J. Haler; L. G. Horsburgh; M. H. Kilgour; H. A. Lewis-Dale; D. G. Mackintosh; A. W. J. Macleod-Carey; H. G. Marchant; Howard Mayes; A. E. Newby; Thomas E. Phythian; Arthur G. Pitt; A. J. Rowledge; W. A. B. Steward; E. E. A. Talbot; W. A. T. Taylor; R. O. Weston; F. W. White; Clement J. Wyke.

Deceases of the following members (with dates of election) were reported during the year:—

1871. Adamson, Joseph
1891. Allen, Marcus
1882. Allen, W. M.
1873. Ashbury, Thomas
1877. Bale, M. Powis
1914. Ball, Sir James B.
1902. Bennett, A. E.
1898. Berry, Thomas (*A.M.*)
1906. Brearley, W. H. (died 1919)
1881. Briggs, John H.
1898. Brindley, Sir H. S. B., K.B.E. (*A.M.*)
1879. Browne, Tomyns R., M.B.E.
1884. Butcher, J. J. (died 1919)
1913. Cartwright, William, Jun. (*A.M.*)
1905. Casson, Robert (*A.M.*)
1905. Clayton, J. A.
1912. Cooke, C. J. Bowen, C.B.E.
1903. Croft, Frederick L.
1905. Cross, R.T.G. (*A.M.*)
1895. Daintree, Thomas E.
1897. Davies, E. J. (died 1919)
1910. Easton, Robert S. (*A.M.*)
1888. Geddes, Christopher (died 1919)
1898. Glen, D. Corse
1912. Goddard, Harold P. (*A.M.*)
1895. Groundwater, Samuel (*A.M.*)
1889. Hall-Brown, Ebenezer
1872. Hartnell, Wilson
1875. Heenan, Hammersley
1879. Higson, Jacob
1885. Hopkinson, Charles
1917. Hunter, James
1897. Ironside, Sir William (*A.M.*) (died 1919)
1884. Kirkaldy, John
1905. L'Estrange, Arthur H.
1904. McCallum, E. A. (died 1919)
1903. McLaren, Sir John, K.B.E.
1873. Mair-Rumley, J. G.
1913. Maitland, Cree
1867. Mather, The Rt. Hon. Sir William, P.C., LL.D.
1905. Maxwell, D. W. F. (died 1919)
1906. Metcalfe, James
1902. Noyes, Edward (*A.*)
1881. Patterson, Anthony
1912. Plowright, J. T.
1908. Pyne, F. D., Major, R.E. (*A.M.*) (died 1919)
1916. Rawlings, P. T., Capt. R.N.V.R. (*A.M.*) (died 1919)
1873. Richardson, John
1887. Roberts, Thomas
1899. Robins, G. Mead
1916. Rogerson, Julian (*A.M.*) (died 1919)
1901. Ross, F. G. (*A.M.*)
1886. Scott, James (Newcastle-on-Tyne)

1875. Tangye, George
1913. Taylor, William Howard (*A.M.*)
1885. Thornley, George
1906. Tulip, Wilfred (*A.M.*)
1917. Wade, E. D. (*A.M.*) (died 1918)
1911. Watson, Robert S. (*A.M.*)
1902. Wayte, J. B., (*A.M.*)
1909. Wilcox, J. G.
1911. Winder, B. W.
1868. Wood, Sir Lindsay, Bart.
1894. Worsdell, Wilson (*Member of Council*)
1913. Wright, Hugh
1877. Wyvill, F. C.

Of these, Sir William Mather, Sir Lindsay Wood, Mr. Joseph Adamson, and Mr. Mair-Rumley were among the oldest Members. Mr. Mair-Rumley served as a Member of Council from 1889 to 1899, and Mr. Wilson Worsdell from 1909.

The Memorial to the eighty-eight Members of the Institution and one Member of the Staff, who had fallen in the War, is now ready to be unveiled in the Entrance Hall. It consists of a mural tablet on which the names of the fallen are embossed in copper.

Early in the year the Secretary, Mr. Worthington, broke down in health, and the Council granted him leave of absence. Subsequently he sent in his resignation which was accepted with much regret. The Council desire to place on record their high appreciation of the services rendered by Mr. Worthington during his long service of twenty-three years, an appreciation they feel sure will be shared by all the Members. To fill the vacancy thus caused, the Council selected Brigadier-General Magnus Mowat, C.B.E., *Member*, for recommendation to the Members, and he was appointed unanimously at the General Meeting in October.

Owing to the continued growth of the work and activities of the Institution, the Council appointed two Assistant Secretaries, namely, Mr. H. T. Chapman for General Business, and Mr. J. E. Montgomrey for technical matters, proposals for membership, and for examinations. Mr. F. W. Ford, who has had charge of the financial department of the Institution for many years, was appointed Accountant, and Mr. A. R. Stock, who had assisted in the work of the Library, etc., was made Librarian.

A total of 115 Council and Committee Meetings were held during the year, being an increase of nearly 30 per cent over 1919. The number of letters received, exclusive of replies to circulars such as those relating to the Summer Meeting, Conversazione, etc., came to 26,725, showing an increase of over 25 per cent of those received during the previous year.

The Accounts for the year ended 31st December 1920 are submitted (*see* pages 18 to 26), having been duly certified by the Auditor. The total revenue was £23,092 0*s.* 7*d.*, while the expenditure was £29,441 19*s.* 10*d.* including £2,000 invested for Reserve Funds.

The total assets amount to £163,012 3*s.* 4*d.*, and deducting therefrom the £34,025 of Debentures, and other liabilities, together with the total amount of the four Reserve Funds, *viz.*, £57,598 8*s.* 0*d.*, the Balance Sheet shows a credit balance of £63,793 6*s.* 3*d.*

The certificates of all securities have been duly verified by the Finance Committee and the Auditor.

No Awards have been made this year for the Water Arbitration Prize and the Thomas Hawksley Gold Medal.

The following Grants were made by the Council, for the year, in aid of the five Researches now being carried on under the direction of the Institution, namely:—

Alloys	£220
Wire Ropes	£100
Steam-Nozzles	£200
Hardness Tests	£100
Cutting Tools	£200

A grant of £25 was made from the Sir Robert Hadfield Prize Fund to Dr. Bernard P. Haigh, M.B.E., for his Paper on "Prism-Hardness" which has been published in the Proceedings (page 891); and one of £10 to Mr. H. Moore, O.B.E., for his Paper on "A small Ball-Hardness Testing-Machine" (page 51). The offer of Prizes will be withdrawn in January 1922 (page 28).

The various Research Committees have continued their work as follows:—

Alloys Research.—The work of this Committee, under the Chairmanship of Sir John Dewrance, K.B.E., has been carried on at the National Physical Laboratory. The Eleventh Report, containing the results of the investigations since the issue of the Tenth Report in 1912, will be presented during the Session 1920–21.

Wire Ropes Research.—This Committee under the Chairmanship of Dr. H. S. Hele-Shaw, F.R.S., has been strengthened by the addition of Sir William E. Smith, C.B., a representative of the British Engineering Standards Association's Sectional Committee on Wire Ropes, Mr. G. H. Roberts, C.B.E., Chief Mechanical Engineer, Woolwich Arsenal, and Professor Henry Louis and Mr. W. C. Mountain, representing the Institution of Mining Engineers. A report entitled "Wire Ropes for use over Pulleys," summarizing the existing literature on the subject, compiled by Dr. W. A. Scoble, Reporter to the Committee, was published in the November Journal. A programme of experimental work to be carried out by Dr. Scoble at the Woolwich Polytechnic is being prepared: in the meantime certain preliminary observations on the behaviour of wire ropes while passing over pulleys are being made, and apparatus is being constructed for the repeated-bending tests over pulleys.

Steam-Nozzles Research.—This Committee, under the Chairmanship of the President, has received a grant of £500 from the B.E.A.M.A. and a further grant of £485 from the Government Department of Scientific and Industrial Research. A contract for the construction of the experimental apparatus to be erected at the Dickinson Street Power Station, Manchester, was concluded. Various apparatus had been lent to the Committee during the course of the year, and the plant was complete by Christmas, experimental work now being in progress. It is intended in the first instance to determine the discharge and efficiency of non-diverging nozzles, the most important form for modern turbines.

Hardness Tests.—The work of this Committee, under the Chairmanship of Dr. W. Cawthorne Unwin, F.R.S., has been carried on at the National Physical Laboratory by Dr, T, E. Stanton, C.B.E., F.R.S. The investigation of Speed effect in Dry Sliding Abrasion Tests, and work on Scratch Hardness Testing and on comparative Ball and Cone Tests have been continued and a Report will shortly be published. A new and interesting instrument for making tests of Scratch-Hardness has been designed at the National Physical Laboratory.

Piston Rings.—The work of this Committee is, owing to various causes, still in abeyance.

Cutting Tools Research.—This Committee, under the Chairmanship of Sir John Dewrance, K.B.E., has been enlarged, and has drawn up an extensive programme of Research Work which involves the appointment of six Panels, with co-ordinated activities. Two of these Panels have already been appointed, No. 1, dealing with "The Tool-Steel and its Treatment," with Colonel R. E. B. Crompton, C.B., as Reporter, and No. 2, considering "Lathe Tools," with Mr. Dempster Smith, M.B.E., as Reporter, and a Sub-Committee, under the Chairmanship of Mr. William Taylor, O.B.E., is investigating the fundamentals of cutting action. A Bibliography on Cutting Tools has been compiled by Mr. G. W. Burley, and will shortly be published. Arrangements are being made for the analysis of this Bibliography in respect of the work of each Panel in order to form the basis of ascertained fact beyond which research will have to be undertaken. Some small-scale cutting tests of the comparative edge-durability of certain tool-steels have been carried out by Colonel Crompton, and arrangements are being made for experimental work on a larger scale, to commence at an early date, under a Research Assistant.

Refrigeration Research.—The work of this Committee, under the Chairmanship of Sir J. Alfred Ewing, K.C.B., which had been completed in respect of its original terms of reference by the publication of its Report in 1914, was suspended during the War. The Department of Scientific and Industrial Research has since appointed an Engineering Committee of the Food Investigation Board of that Department, for the purpose of carring out researches in Refrigeration. That Committee, which is also under the Chairmanship of Sir Alfred Ewing, is now actively engaged on researches of the same character as those which had been contemplated by the Committee of the Institution. In the circumstances, it did not seem desirable to maintain the Institution Committee, and (at its own suggestion) it has been dissolved.

Oil-Engines Nomenclature Committee.—Arising out of the discussion on the Paper on "Some Lincolnshire Oil-Engines" at the Lincoln Summer Meeting, the Council appointed a Committee to consider the question of the Nomenclature of Oil-Engines. The difficulties of reconciling the claims of inventors with scientific facts, and of making recommendations likely to prove acceptable to firms engaged in the manufacture of Oil-Engines, are obvious, but it is hoped that the labour of this Committee may at least result in the eradication of certain unscientific terms now commonly in use.

Alterations of By-Laws re Membership Applications.—The alteration of By-Laws which took place in February and March has resulted in raising the standard for admission to the Institution. An examination qualification is now compulsory up to the age of 33 and the Proposal Forms approved by the Council provide for a fuller and more explicit statement of the Candidate's career and responsibilities. Instead of obtaining the signatures of supporters, not all necessarily from personal knowledge, the Candidate is now required to give the names of three referees, two of whom at least must be corporate Members of the Institution, and it has been found that more complete evidence as to the qualifications of Candidates is thus obtained. At the same time, by publication in the Journal of the designation of each Candidate at least a month before his case is considered by the Council, an opportunity is given to members, which the Council trust they will use, of safeguarding the Institution against the election of undesirable Candidates in a more effective manner than was possible when election was by ballot. All communications with regard to Candidates are treated by the Council as confidential.

Admission of Officers of H.M. Forces.—A number of applications for membership have been made by Officers serving in technical Units of H.M. Forces, whose mechanical engineering training has been necessarily of a different nature to that of civilian engineers. It has not been found possible to lay down any general rules defining the qualifications which should be demanded of such Candidates, and the Council have considered each case on its merits, according to their qualifications as Mechanical Engineers.

Admission of Women.—The question of the admission of women to the Institution has been raised during the year. The Council have been advised that the effect of the Sex Disqualification (Removal) Act 1919, is to open the Institution to women on equal terms with men. They will accordingly consider any applications for membership which may reach them, but so far they have received none in which evidence is given of sufficient compliance with the By-Laws.

Examinations.—The Institution Examinations were held in April and October, when 62 Candidates passed the Graduateship and 61 the Associate Membership Examinations. A prize of the value of £5 was awarded to William Abbott in the April Associate Membership Examination, and prizes of the value of £3 each to W. H. Morris and A. C. Page in the April and October Graduateship Examinations respectively.

The Council have had under their very careful consideration the difficult position of Candidates for admission whose careers had been interrupted to a serious extent by service in H.M. Forces throughout the War, and who, since their demobilization, have secured positions of responsibility which prevent them from studying for the Associate Membership Examination. In some such cases it has been found possible, by personal interviews with the Candidates, and a close scrutiny of the records of their general and technical education, to decide that they possessed a standard of literary and scientific knowledge equivalent to that demanded in the qualifying examination for Associate Membership.

Informal Meetings.—A new departure was made during the year in holding Informal Meetings for the discussion of various Engineering topics on the Friday evenings during the session not occupied by other functions. The number so held has been 12 and the average attendance about 40, about one-third of the members present having taken part in the discussions.

The Meetings have been held in the Reading Room, where smoking is permissible, a wide variety of subjects has been discussed, and the Council are of opinion that the Meetings have served a useful purpose as regards the interchange of knowledge, social intercourse, and practice for younger members in the art of public speaking.

External Technical Training.—The Council have had under consideration requests from Government Departments and other outside bodies for advice or assistance in matters relating to mechanical engineering training. They are at present engaged in co-operation with the Air Ministry on the engineering training of Officers appointed to Short Service commissions in the Royal Air Force, the object being to fit such Officers as far as possible to take up the profession of mechanical engineering when their period of service in H.M. Forces is completed.

A Grant of £50 for the year 1920 has been made towards the expenses of the Conjoint Board of Scientific Societies, on which the Institution has two Representatives.

The Council desire to thank the members and others who have made presentations to the Library. A complete list of additions will be found on pages 31–50.

In the early part of the year the Council invited Dr. W. Cawthorne Unwin, F.R.S., *Past-President*, to allow his portrait to be painted for the Institution, in recognition of his great services to this Institution and to the Engineering Profession. An excellent three-quarter length portrait was executed by Mr. Harold Speed, and is now hanging in the Council Room.

Meetings and Papers.—Monthly General Meetings were held during the year, with the exception of May, June, August, and

September. These Meetings were occupied with the reading and discussion of the following Papers:—

Recent Advances in Utilization of Water-Power; by Eric M. Bergstrom, *Associate Member.*

Exact Data on the performance of Mechanical Stokers as applied to "Lancashire" or other narrow-flued Boilers; by David Brownlie, *Associate.*

The Hardening of Screw-Gauges with the least Distortion in Pitch (referring to Water Hardening and Oil Hardening); by the late Wilfrid J. Lineham, B.Sc., *Member.* (Revised by G. T. White, B.Sc.)

Roman Lincoln; by Lieut.-Col. E. Mansel Sympson, M.A., M.D., F.S.A.

Recent Excavator Practice; by F. H. Livens and W. Barnes, *Members.*

Road Transport by Steam-Vehicles; by P. W. Robson, O.B.E.

Some Lincolnshire Oil-Engines; by F. H. Livens, *Member.*

The Human Factor in Industry; by A. Ramsay.

The Uniflow Steam-Engine; by F. B. Perry, *Member.*

Note on new Power Station for Messrs. Marshall, Sons and Co., Gainsborough; by F. J. Cribb, *Member.*

Address by the President, Captain H. Riall Sankey, C.B., C.B.E., R.E., ret.

Sterilization of Water by Chlorine Gas; by Captain J. Stanley Arthur, O.B.E., B.Sc., A.I.C., R.A.M.C. (T.F.)

Thermodynamic Cycles in relation to the Design and Future Development of Internal-Combustion Motors; by William J. Walker, Ph.D., *Associate Member.*

The following Paper was accepted for publication in the Proceedings, with discussion in writing:—

The Coefficient of Discharge of Elementary Nozzles, by A. A. Jude, *Member.*

The following Papers were accepted for publication in the Proceedings:—

Wire Ropes for use over Pulleys: Preliminary Report to the Wire Ropes Research Committee; by Walter A. Scoble, D.Sc., *Member.*

Helical Springs; by W. Norman Thomas, M.Sc., *Associate Member.*

Prism-Hardness: A new method of testing Hardness in Materials; by Bernard P. Haigh, M.B.E., D.Sc.

The Measurement of High Degrees of Hardness; by John Innes.

Hardness Testing, by means of two new types of Machines; by H. S. Primrose and J. S. Glen Primrose, *Associates.*

"Thomas Hawksley" Lecture.—Sir Richard T. Glazebrook, K.C.B., Sc.D., F.R.S., *Honorary Life Member*, delivered the seventh "Thomas Hawksley" Lecture, on "Limit Gauging" (Proceedings 1920, page 1075), in London on 5th November. The Lecture was repeated by Sir Richard Glazebrook in Manchester, Birmingham, and Glasgow.

Local Correspondents.—The thanks of The Institution have been expressed to the following members who kindly acted as Honorary Local Correspondents during the Session 1919–20:—

Mr. Guy L. Drury (Newcastle-on-Tyne).
Mr. Frederick Grover (Leeds).
Mr. John W. Hall (Birmingham).
Professor A. L. Mellanby, D.Sc. (Glasgow).
Professor W. Ripper, C.H., D.Eng., D.Sc. (Sheffield).
Mr. David E. Roberts (Cardiff).
Mr. Dempster Smith, M.B.E. (Manchester).

Six Local Meetings were held in Manchester, two in Birmingham, and one in Glasgow, for the further discussion of Papers presented in London. Invitations were extended to the Members of the Local Engineering Societies to attend and take part in these Meetings.

Local Branches.—Following the adoption of new By-laws 44 to 48, relating to Local Branches (Proceedings 1920, page 245), the Council have acceded to Petitions for the formation of Local Branches of the Institution in Birmingham, Leeds, and Manchester.

The first Meeting of members in each of these localities will be held at an early date, when the Local Committee will be appointed and Rules formulated for the carrying on of the Branch.

Calcutta and District Section.—At the request of the local Members, the Council have consented to the merging of the Section, with the funds, into the Bengal Association of the Institution of Engineers (India).

Council.—In the autumn, Extraordinary General Meetings were held, at which a Resolution was passed, and confirmed, with the object of increasing the rate of promotion through the Council. In future the Council will comprise not more than four Past-Presidents, not more than three Past-Vice-Presidents, and Chairmen of Local Branches, in addition to the President, Vice-Presidents, and Ordinary Members of Council (*see* Proceedings, 1920, pages 961–2).

Summer Meeting.—The Summer Meeting, which function had to be abandoned during the War, was held in Lincoln, 20th to 23rd July. Lieut-Colonel J. S. Ruston acted as Chairman of the Reception Committee, consisting of members in the locality and other influential gentlemen. Mr. Alfred E. Collis, *Member*, kindly acted as Honorary Local Secretary. Visits were arranged to the Works and places of interest in Lincoln, and to Newark, Gainsborough, and Scunthorpe. The attendance at the Meeting was 175 members, 20 visitors, and 63 ladies.

A Conversazione was held in the Institution Building in October, the first since 1914, and the Members and Visitors were received by the President and Mrs. Sankey, and the Council.

Graduates.—The Graduates' monthly Meetings during the Session 1919-20 were occupied by the reading and discussion of seven Papers, the titles of which were published in the October Journal, and a Prize of £5 was awarded to Mr. T. F. Davey (*G.*) for his Paper on "The Manufacture of British Association Screw-Thread Gauges," and one of £3 to Mr. F. M. Green (*G.*) for his Paper on "Modern Steam-Turbines."

At the April Meeting, the Students of The Institution of Civil Engineers and of The Institution of Electrical Engineers were invited to attend a Joint Meeting to discuss "The Six-Hour Working Day and its Effect on Industry," and it is hoped that similar Joint Meetings will become a feature in future Sessions.

The Engineering Societies of the Universities of Birmingham, Bristol, Cardiff, Edinburgh, Glasgow, Liverpool, and Manchester, and of Armstrong College, Newcastle-on-Tyne, have again kindly invited the Graduates in those localities to attend their Meetings during the Session.

Arising from the Discussion at the Annual General Meeting on the question of admitting students and apprentices to some of the privileges of Graduateship, a Committee was appointed to consider the matter, and the Council have decided that these young men, (to be styled Student Visitors), should be permitted to receive the Journal annually at the charge of £1, together with a ticket entitling them to attend the Meetings of the Institution.

Civil Engineers' Registration Bill.—The Institution of Civil Engineers advertised a Bill to be entered in Parliament dealing with the Registration of Civil Engineers. As it appeared to the Council that the proposed measure might interfere with the freedom and status of the Members of this Institution, representations were made to the Institution of Civil Engineers. After some friendly discussion with the latter, and other Institutions, the matter was held back for further consideration, the result of which it is hoped will be of benefit to the profession and to the nation.

Watt Memorial.—An appeal was made to the Institution in 1919 on behalf of a Memorial to be founded in Birmingham upon the occasion of the centenary of the death of James Watt. As a Memorial merely, the Institution had no power under its Articles to subscribe to the fund, but the scheme included the erection and equipment of a building in the City of Birmingham, which should serve not only as a Watt Museum but also as a Library and Meeting place, and probably as Headquarters, for the Local Engineering Institutions. This offered such direct advantage to members of the Institution, especially in view of the projected Local Branch at Birmingham, that the Council (after taking legal advice) offered a contribution of £2,000 payable as the work progressed and subject to its taking a form clearly useful to the Members and Associate Members in the district.

Proposed Closing of Finsbury Technical College.—The proposal of the City and Guilds of London Institute to close the Finsbury Technical College at the end of the Session 1920–21, owing to financial reasons, has received the attention of the Council. In view of the great need existing for facilities for technical education, and the fact that Scientific Schools and Colleges in all parts of the Kingdom are overcrowded, it was decided that an appeal should be addressed to the Institute asking them to review their decision, as it was thought very undesirable that the College with its valuable organization and equipment should be closed. A letter has accordingly been addressed by the Presidents of sixteen of the leading Technical Institutions to the Earl of Halsbury, the Chairman of the City and Guilds of London Institute, and copies of the letter have been sent to representatives of the Corporation of London, the London Livery Companies, etc., upon the City and Guilds of London Institute, and it is hoped that they will see their way to make such arrangements as will permit the College remaining open for at least three years, or until the great stress caused by the War has passed.

The Council have been pleased to grant the loan of the Meeting Hall on various occasions to several kindred Institutions.

The Institution has been represented on the—

Courts of the Universities of Bristol, Liverpool, and Sheffield.
Governing Board of the Imperial College of Science and Technology.
General Committee of the Royal Society for administering the Government Grant for Scientific Investigations.
National Physical Laboratory.
Engineering Committee of the Government Department of Research.
British Engineering Standards Main Committee and Sectional Committees.
School of Metalliferous Mining (Cornwall).
London Committee of the University of Hong Kong.

Conjoint Board of Scientific Societies, organized by the Royal Society.

Royal Sanitary Institute Congress.

Treasury Selection Board for posts in Ministry of Transport, etc.

Conference on Training of technical Officers in the Civil Service.

Association for Grey and Malleable Cast Iron Research.

Committee appointed by the Army Council re Corps or Engineer Pay of Officers in Technical Corps

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Benevolent Fund.

This Fund now comprises 103 Life Members, and 363 Ordinary Members subscribing not less than Half-a-Guinea. Legacies have been left to the Fund under the Wills of the late Mr. Thomas Roberts, of Adelaide (£100 duty free), and the late Mr. J. G. Mair-Rumley (£250). A Form of Bequest may be obtained from the Hon. Secretary. The Committee of Management has been able to make several Grants during the year to necessitous cases.

Dr. ACCOUNT OF REVENUE AND EXPENDITURE

Expenditure.

	£	*s.*	*d.*	£	*s.*	*d.*
To Expenses of Maintenance and Management—						
Salaries and Wages, and Pension	8,150	3	11			
Postages, Telegrams, and Telephone	1,423	5	5			
Heating, Lighting, and Power	268	12	4			
Fittings and Repairs	332	16	7			
Housekeeping	361	10	7			
Incidental Expenses	116	2	10			
				10,652	11	8
,, Printing, Stationery, and Binding—						
Printing and Engraving Journal	5,495	6	2			
Stationery and General Printing	2,615	18	2			
Binding	215	16	6			
				8,327	0	10
,, Rent, Rates, Taxes, &c.—						
Ground Rent (Birdcage Walk)	1,107	17	2			
Do. No. 5 Princes Street	135	0	0			
Rates and Taxes	2,062	5	7			
Insurance	190	16	4			
				3,495	19	1
,, Meeting Expenses—						
Printing	774	5	8			
Travelling and Incidental Expenses	239	17	6			
Reporting	94	15	7			
Local Meetings	125	15	3			
				1,234	14	0
,, Reception				412	10	6
,, Dinner Expenses				255	18	0
,, Portrait of Dr. W. Cawthorne Unwin, F.R.S.				279	6	0
,, Council Prizes				21	7	0
,, Books purchased				102	19	10
,, Examinations				504	7	0
,, Researches				600	8	9
,, Donation to Conjoint Board of Scientific Societies				50	0	0
,, Depreciation on Furniture and Fittings				143	17	2
,, Debenture Interest				1,361	0	0
,, Debenture Redemption Sinking Fund				1,000	0	0
,, Staff Pensions Fund				1,000	0	0
				£29,441	19	10

FOR THE YEAR ENDED 31st DECEMBER 1920. *Cr.*

Revenue.

	£	s.	d.
By Subscriptions for 1920	18,102	10	0
,, Subscriptions in arrear, paid in 1920	1,250	0	0
,, Entrance Fees	1,075	10	0
,, Rents of Institution Building	1,588	0	0
,, Bank Deposit Interest	140	18	0
,, Sale of Proceedings, Journals, and Bound Volumes—*Extra Copies sold*	635	9	1
,, Examination Fees	299	3	6
,, Debenture Transfer Fees	0	10	0
Total Revenue	23,092	0	7
,, Debit Balance (exclusive of value of Subscriptions in arrear), carried to Balance Sheet	6,349	19	3
	£29,441	19	10

BALANCE SHEET

Dr.

	£ s. d.	£ s. d.	£ s. d.
To 4% Debentures (1912 Issue):—			
327 *Debentures of £100 each*		32,700 0 0	
23 *Debentures of £50 each*		1,150 0 0	
7 *Debentures of £25 each*		175 0 0	34,025 0 0
,, Sundry Creditors—			
Accounts owing at 31st Dec. 1920		5,406 10 10	
Unclaimed Debenture Interest (coupons not presented)		172 6 5	5,578 17 3
,, Piston-Rings Research (Investment of Mr. Williamson's donation of £500 and Interest), *per contra*		537 5 10	
,, Steam-Nozzles Research (balance of Grants and Interest) *per contra*		1,104 16 0	1,642 1 10
,, Subscriptions paid in advance			374 10 0
,, Reserve Funds (see pages 22–3) *per contra*—			
Debenture Redemption Sinking Fund		11,487 3 5	
Leaseholds Amortisation ,, ,,		24,346 0 1	
Staff Pensions Fund		3,703 14 9	
General Reserve Fund		18,061 9 9	57,598 8 0
,, Balance, being Capital of the Institution, exclusive of the Reserve Funds:—			
Balance at 31st *Dec.* 1919		69,563 8 0	
Deduct—			
Excess of Expenditure over Revenue for the year ended 31st *Dec.* 1920	6,349 19 3		
Balance of Govt. Grant for Steam-Nozzles Research, and Interest, transferred to account of that Research	161 12 6	6,511 11 9	
		63,051 16 3	
Add—			
Amount received from Life Compositions during 1920		741 10 0	63,793 6 3
			163,012 3 4
,, Trust Funds (see pages 24–6), *per contra*			4,794 18 0
			£167,807 1 4

Signed by the following Members of the Finance Committee:—

Mark Robinson (*Chairman*).
W. H. Maw.
H. S. Hele-Shaw.

Christopher James.
W. H. Patchell.
Lough. Pendred.

R. Williamson.

AT 31st DECEMBER 1920. *Cr.*

			£ s. d.
By Cash (exclusive of Reserve and Trust Funds)— In National Provincial and Union Bank of England—		£ s. d.	
On Current Account		344 10 5	
Less Cheque outstanding . .	175 0 0		
,, Piston-Rings Research, Interest, ...	37 5 10		
		212 5 10	
		132 4 7	
In the Secretary's hands		38 19 3	
			171 3 10
,, Amount in National Provincial and Union Bank of England to meet unclaimed Debenture Interest (*coupons not presented*)			172 6 5
,, Piston-Rings Research (Investment of Mr. Williamson's donation of £500 and Interest), *per contra*		537 5 10	
,, Steam-Nozzles Research (balance of Grants and Interest), *per contra*		1,104 16 0	
			1,642 1 10
,, Reserve Funds, Investments and Cash in Bank for investment (see pages 22–3), *per contra*			57,598 8 0
,, Subscriptions in arrear, *not valued.*			
,, Furniture and Fittings (*less depreciation*)			1,294 14 8
,, Books in Library, Drawings, Engravings, Models, Specimens, and Sculpture (*estimate of* 1893)			1,340 0 0
,, Proceedings—stock of back numbers, *not valued.*			
		£ s. d.	
,, Institution House . . . . *Cost*		60,270 2 10	
,, Princes Street Extension . . . . . . ,,		40,523 5 9	
Depreciation covered by Leaseholds Sinking Fund, per contra			100,793 8 7
			163,012 3 4
,, Trust Funds (Investments and Cash in Bank, see pages 24–6), *per contra*—		£ s. d.	
Willans Premium Fund		174 15 8	
Water Arbitration Prize Fund		536 17 11	
Starley Premium Fund		452 18 10	
Bryan Donkin Fund		393 2 3	
Thomas Hawksley Fund		2,545 9 9	
Sir R. Hadfield Prize Fund		154 2 7	
T. Bernard Hall Prize Fund		537 11 0	
			4,794 18 0
			£167,807 1 4

I have examined the above Balance Sheet and report that I have obtained all the information and explanations I have required. In my opinion such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of the information and explanations given to me and as shown by the Books of the Institution.

RAYMOND CRANE, F.C.A.,
Auditor,
46/47 London Wall, London, E.C.

17*th January* 1921.

DEBENTURE REDEMPTION SINKING FUND.

(Constituted on 18th May 1917.)

	£	s.	d.	£	s.	d.
Investment £10,865 5% War Stock 1929–1947 *cost*	10,201	2	6			
Do. £1,000 5¾% Exchequer Bonds 1925 ,,	1,000	0	0			
Do. £350 4% Funding Stock . . ,,	280	0	0	11,481	2	6
Cash Balance				6	0	11
Total, as per Balance Sheet				£11,487	3	5

LEASEHOLDS AMORTISATION SINKING FUND.

(Constituted on 18th May 1917.)

	£	s.	d.	£	s.	d.
Investment £24,750 5% War Stock 1929-1947 *cost*	23,302	13	6			
Do. £1,300 4% Funding Stock. . ,,	1,040	0	0	24,342	13	6
Cash Balance				3	6	7
Total, as per Balance Sheet				£24,346	0	1

STAFF PENSIONS FUND.

		£	s.	d.
Investment £700 L. & S. W. Rly. 3% Consolidated Deb. Stock. *Market Value at 18th May* 1917		420	0	0
Do. £2,700 12*s.* 1*d.* 4% Funding Stock . . .	*cost*	2,156	8	2
Do. £1,000 5¾% Exchequer Bonds 1925 . .	„	1,000	0	0
		3,576	8	2
Cash Balance		127	6	7
Total, as per Balance Sheet		£3,703	14	9

GENERAL RESERVE FUND.

£	s.	d.	Investments—		£	s.	d.
5,408	0	0	L. & N. W. Ry. 3% Debenture Stock.				
5,080	12	0	Midland Ry. 2½% Debenture Stock.				
3,084	10	8	Metropolitan Water (B) 3% Stock.				
1,586	0	0	London County 3½% Consolidated Stock.				
670	0	0	L. & S. W. Ry. 3% Consolidated Deb. Stock.				
			Market Value at 18th May 1917		9,286	18	2
			Investment £3,044 4*s.* 10*d.* 4% Funding Stock . . .	*cost*	2,317	10	11
			Do. £7,450 Do. (*trans. by Deed*) .	„	5,976	2	8
					17,580	11	9
			Cash Balance		480	18	0
			Total, as per Balance Sheet . . .		£18,061	9	9

WILLANS PREMIUM FUND.

(*Subscribed*, 1897, *by friends of the late P. W. Willans, to commemorate the services he rendered to Engineering and Electrical Science.*)
(Under a Joint Trust with The Institution of Electrical Engineers.)

	£ s. *d.*	£ s. *d.*
Investment £159 8*s.* 5*d.* of India 3% Stock . . . . . . *cost*		165 5 0
Cash Balance from 1919	4 15 4	
Interest received in 1920	4 15 4	
		9 10 8
Total, as per Balance Sheet		174 15 8

(For Declaration of Trust, *see* Proceedings 1918, page 23.)

WATER ARBITRATION PRIZE FUND.

(*Presented by the late Sir Edward Fry and the Metropolitan Water Board, to commemorate the holding, in the Institution building, of the Court of Arbitration*, 1903–5, *relating to the purchase of the Undertakings of the eight London Water Companies.*)

	£ *s.* *d.*	£ *s.* *d.*
Investment £523 10*s.* 2*d.* of Metropolitan Water (B) 3% Stock *cost*		500 0 0
Cash Balance from 1919	21 3 11	
Interest received in 1920	10 19 10	
Income Tax refunded in 1920	4 11 2	
		36 17 11
Total, as per Balance Sheet		536 17 11

(For Regulations, *see* page 27.)

STARLEY PREMIUM FUND.

(*Presented*, 1906, *by the J. K. Starley Memorial Committee.*)

	£ *s.* *d.*	£ *s.* *d.*
Investment £435 8*s.* 5*d.* of London County 3½% Consolidated Stock . . . . *cost*		440 7 6
Cash Balance from 1919	42 0 8	
Interest received in 1920	10 13 4	
Income Tax refunded in 1920	4 11 4	
		57 5 4
		497 12 10
Award to Mr. L. A. Legros, O.B.E.		44 14 0
Total, as per Balance Sheet		£452 18 10

(For Declaration of Trust, *see* Proceedings 1916, page 25.)

BRYAN DONKIN FUND.

(*Bequest*, 1909, *under the Will of the late Bryan Donkin, Vice-President* 1901-2.)

	£	s.	d.	£	s.	d.
Investment £349 15*s*. 8*d*. of London County 3½% Consolidated Stock . . . . *cost*				360	6	6
Cash Balance from 1919	20	11	1			
Interest received in 1920	8	11	8			
Income Tax refunded in 1920	3	13	0			
				32	15	9
Total, as per Balance Sheet				£393	2	3

(For Regulations, *see* page 27.)

THOMAS HAWKSLEY FUND.

(*Established by the late Charles Hawksley, Member of Council* 1913-1917, *to commemorate the Centenary on* 12*th July* 1907 *of the birth of his Father, the late Mr. Thomas Hawksley, F.R.S., President* 1876-1877 (*died* 23 *Sept.* 1893).)

	£	s.	d.	£	s.	d.	£	s.	d.
Capital—									
£1,300 *Southend Waterworks Co.* 4% *Perpetual Debenture Stock* . . . . *nominal value*				1,300	0	0			
£700 *Lowestoft Water and Gas Co.* 4% *Debenture Stock* . . . . *nominal value*				700	0	0			
Accumulated Interest (invested)—									
£420 *G. W. Ry.* 4½% *Debenture Stock* . *cost*				499	14	6			
							2,499	14	6
Cash Balance from 1919				183	13	7			
Interest received in 1920				69	4	8			
Income Tax refunded in 1920				29	13	5			
				282	11	8			
Mr. John Pinches, making 9 gold medals	154	16	0						
Lecturer, 1920	82	0	5						
				236	16	5			
							45	15	3
Total, as per Balance Sheet							£2,545	9	9

(For Declaration of Trust, *see* Proceedings 1915, page 25.)

SIR ROBERT HADFIELD PRIZE FUND.

(*Presented*, 1917, *by Sir Robert A. Hadfield, Bart., D.Sc., D.Met., F.R.S., Vice-President, to provide* (1917–1921 *inclusive*) *a prize or prizes for the description of a new and accurate method of determining the Hardness of Metals.*)

	£ s. d.	£ s. d.
Investment £150 5% War Stock 1929–1947 (*Bonds*) . . *cost*		142 10 0
Cash Balance from 1919	28 15 1	
Interest received in 1920	5 5 0	
Income Tax refunded in 1920	2 12 6	36 12 7
		179 2 7
Award to Dr. B. P. Haigh		25 0 0
Total, as per Balance Sheet		£154 2 7

(For Conditions, *see* page 28.)

T. BERNARD HALL PRIZE FUND.

Presented, 1917, *by Mr. T. Bernard Hall, Member, for the provision of prizes for original communications dealing with invention, design, or research in Mechanical Engineering, presented to the Institution.*)

	£ s. d.	£ s. d.
Investment, £500 5% War Stock 1929–1947 (*transferable by Deed*) *nominal value*		500 0 0
Cash Balance from 1919	62 10 0	
Interest received in 1920	25 0 0	87 10 0
		587 10 0
Award to Dr. W. H. Hatfield		49 19 0
Total, as per Balance Sheet		£537 11 0

(For Conditions, *see* page 30.)

WATER ARBITRATION PRIZE.

Regulations for the Seventh Award, to be made in February 1923.

1. The Award will be made for the best original Paper dealing with INTERNAL-COMBUSTION ENGINES, accepted by the Council for publication with or without discussion in The Institution Proceedings of 1921 and 1922, provided that the Paper be of sufficient merit in the judgment of the Council.

2. Papers should be sent in as soon as possible, but not later than 1st April 1922.

3. Papers should be illustrated by scale drawings, but may be accompanied by photographs, lantern-slides, and specimens.

4. Any Paper not accepted for printing in the Proceedings will be returned to the Author.

5. The Prize will have the value of about £30, and will be accompanied by a Certificate bearing the Seal of The Institution.

BRYAN DONKIN FUND.

Fifth Award, to be made in February 1922.

1. The Bryan Donkin Award, consisting of the interest on the sum of £360 6*s*. 6*d*., shall be made triennially (beginning in February 1910) by the Council, as a grant or grants in aid of original research in Mechanical Engineering.

2. Applications for grants must be received at The Institution on or before 31st October in the year immediately preceding the year of the next Award. Each application must be accompanied by the names and addresses of two references as to the ability of the applicant to undertake the proposed research, and must contain a concise statement as to the nature of the research and the sum applied for, with details of the proposed expenditure.

3. All applications received in accordance with Clause 2 shall be considered by the Council, on a Report from the Research Committee. The Council shall decide as to the allocation of the sum available, and if it is considered that none of the applicants

is deserving of a grant, or if the grants made amount to less than the sum available, the surplus shall be devoted to aiding any of the Researches of The Institution, and shall be distributed in such proportions as the Council shall decide.

4. The full amount of each grant made by the Council shall be handed over to the applicant at his request. If no request for payment is received within six months the grant shall lapse.

5. Any portion of a grant not expended by 31st December in each year shall be forthwith returned to The Institution, unless permission in writing has been previously received from The Institution for its retention, in order to continue the research.

6. The recipient of a grant shall send to The Institution on each 1st January during the continuation of his research a Report of his progress, with particulars of the expenditure incurred, accompanied as far as possible by vouchers. He shall also, at the request of the Council, send to The Institution a statement of his experiments and the results obtained; and the Council shall be at liberty to publish the same in the Proceedings of The Institution.

7. Any recipient of a grant who fails to fulfil the conditions in Clause 6, or whose Report is not considered satisfactory by the Council, may be required to return to The Institution the whole amount granted to him.

SIR ROBERT HADFIELD PRIZE.

For a new Method of determining the Hardness of Metals.

First Award was made in January 1918.

Conditions of Award.

1. Sir Robert A. Hadfield, D.Sc., D.Met., F.R.S., placed in January 1917 in the hands of The Institution of Mechanical Engineers the sum of £200, which with any income therefrom may be awarded at the discretion of the Council of The Institution as a Prize or as Prizes, for the description of a new and accurate method

of determining the hardness of metals, especially of metals of a high degree of hardness.

2. The ordinary tests of hardness, such as are described in the Report of the Hardness Tests Research Committee (Proceedings of The Institution of Mechanical Engineers, 1916, pages 677 to 778), which should be consulted by competitors, fail to some extent when the hardness of the material exceeds about 600 to 800 Brinell. What is desired is the description of a research for or an investigation of some method of determining hardness accurately, suitable for application in metallurgical work in cases in which present methods partially fail.

3. The Award or Awards will be made by the Council of The Institution of Mechanical Engineers, whose decision will be in all cases final.

4. The Council will consider annually all communications received, and may then award a Prize or Prizes. But in January 1922 the offer of Prizes will be withdrawn, and any unexpended balance of the Prize Fund will be diverted to any other purposes to be determined at the discretion of the Council.

5. The Council may award the whole or any part of the sum available at any time if a communication is received which, in their opinion, is of sufficient originality and importance and satisfies the object aimed at; or they may from time to time award portions of the Fund, not exceeding in all £75 in any one year, for communications which do not completely solve the problem, but which appear to advance the knowledge of methods of testing hardness. The Institution will probably be willing and reserve the right to publish in its Journal any communications for which a prize is awarded.

6. A communication should be accompanied by scale drawing of any new apparatus described, or by a model or an example of the apparatus itself. If the communication describes a new invention, likely to be of commercial value, it is desirable that provisional protection should have been obtained before it is submitted for consideration.

7. Communications should be addressed to The Secretary, The

Institution of Mechanical Engineers, Storey's Gate, St. James Park, London, S.W. 1, and marked "Method of determining Hardness," and should reach him at least one month before the 1st January in any year.

T. BERNARD HALL PRIZES.

Second Award, to be made in February 1922.

Conditions of Award.

A sum of Five Hundred Pounds having been offered by Mr. T. Bernard Hall (Member) for the provision of prizes for original Communications dealing with invention, design, or research in Mechanical Engineering presented to The Institution, the Council hereby give notice :—

1. A medal prize or prizes of an aggregate value not exceeding two years' net income of the Trust Fund may be awarded every second year to the Author or Authors of any original Communication or Communications dealing with invention, design, or research in Mechanical Engineering, published in the Proceedings of The Institution during the preceding two years, and which in the opinion of the Council shall be of sufficient merit.

2. The award or awards will be made by the Council of The Institution of Mechanical Engineers, whose decisions will be final in all cases.

3. Should the value of the awards made at the end of any biennial period be less than the income for the period, the balance may be added to the capital of the Fund or may be used for assisting researches at the discretion of the Council.

LIST OF ADDITIONS TO THE LIBRARY AND READING ROOM.

BOOKS, see below.
OFFICIAL PUBLICATIONS, see p. 37.
PAMPHLETS, see p. 40.
DIRECTORIES, ANNUALS, &c., see p. 42.
CALENDARS and COLLEGE REPORTS, see p. 43.
DRAWINGS, &c., see p. 43.
PUBLICATIONS OF SOCIETIES, &c., see p. 44.
PERIODICALS, see p. 48.

BOOKS (in order received).

Transmission Gears, Mechanical, Electric, and Hydraulic, for Land and Marine Purposes, by Edward Butler.

A Treatise on British Mineral Oil, edited by J. A. Greene; from the Kershaw Donation.

Mnemonic Notation for Engineering Formulæ: Report of the Science Committee of the Concrete Institute, with explanatory notes by E. F. Etchells; from the publishers.

Diesel Engine Design, by H. F. P. Purday; from the publishers.

Chemists' Manual of Non-Ferrous Alloys, by J. R. Downie; from the publishers.

Electricity and Magnetism for Engineers, Part I: Electric and Magnetic Circuits; Part II: Electrostatics and Alternating Currents, by Harold Pender, Ph.D.

Structural Steelwork: relating principally to the construction of Steel-framed Buildings, by E. G. Beck; from the publishers.

The Management Problem, by E. T. Elbourne; from the author.

A System of Physical Chemistry, by W. C. McC. Lewis, D.Sc. (2nd ed.) in three volumes. Vol. I: Kinetic Theory; Vol. II: Thermodynamics; Vol. III: Quantum Theory; from the Kershaw Donation.

The Chemical Analysis of Iron: A complete Account of all the best-known Methods for the Analysis of Iron, Steel, Pig-Iron, Alloy Metals, Iron Ore, Limestone, Slag, Clay, Sand, Coal and Coke, by A. A. Blair; from the Kershaw Donation.

Motor Vehicles and their Engines: A Practical Handbook on the Care, Repair, and Management of Motor Trucks and Automobiles for Owners, Chauffeurs, Garagemen, and Schools, by E. S. Fraser and R. B. Jones.

Flow and Measurement of Air and Gases, by A. B. Eason; from the Kershaw Donation.

Tidal Power: Its Practical and Economical Utilization, by W. T. Taylor; from the author.

A Text-Book on Machine Drawing for Electrical Engineers, forming an Introductory Treatise on the Construction of Electrical Machinery and Apparatus, by E. Blythe; from the publishers.

A Text-Book of Aeronautical Engineering, by A. Klemin.

Electric Mains and Distributing Systems, by J. R. Dick and F. Fernie. (2nd ed.).

The Manufacture of Chemicals by Electrolysis, by A. J. Hale.

Piece-rate, Premium and Bonus, by J. E. Prosser.

Practical Electric Welding, by H. B. Swift.

Wireless Transmission of Photographs (2nd ed.), by M. J. Martin; from the publishers.

Selected Studies in Elementary Physics: A Handbook for the Wireless Student and Amateur, by E. Blake; from the publishers.

Wireless Telegraphy and Telephony: First Principles, Present Practice and Testing, by H. M. Dowsett; from the publishers.

Wire and Sheet Gauge Tables (2nd ed.), compiled by T. Stobbs; from the publishers.

Coal-Tars and their Derivatives, by G. Malatesta; from the publishers.

The following thirteen works are presented by Dr. W. Cawthorne Unwin:—

A Treatise on Machine Tools, etc., as made by Wm. Sellers and Co. (6th ed., 1884).

Die Steurungen der Dampfmaschinen, by E. Blaha (1885).

Strength and Elasticity of Structural Members, by R. J. Woods (1903).

The Mechanics of Pumping Machinery, by J. Weisbach and G. Herrmann (1897).

The Mechanics of Hoisting Machinery, by J. Weisbach and G. Herrmann (1893).

Die Kraftübertragung auf weite Entfernungen, by G. Meissner (1883).

Theory of Structures and Strength of Materials, by H. T. Bovey (1893).

The Mechanical Handling of Material, by G. F. Zimmer (1905).

Lehrbuch der Eisen-Constructionen, by E. Brandt (1876).

Enveloppes de Vapeur dans les Machines Compound, by A. Witz (1893).

Report of the Royal Commission of Inquiry into the Alleged Defectiveness and Unsuitability of the Baldwin Locomotives (1892).

Schnell-Betrieb, by A. Riedler (1899).

An Investigation of the Coals of Canada with reference to their Economic Qualities (7 vols., 1912–1915).

The Use of Low-Grade and Waste Fuels for Power Generation, by J. B. C. Kershaw; from the publishers.

American Hydro-electric Practice: a compilation of Useful Data and Information on the Design, Construction and Operation of Hydro-electric Systems from the Penstocks to Distribution Lines, by Wm. T. Taylor and D. H. Braymer; from Mr. William T. Taylor.

Zinc and Its Alloys, by T. E. Lones.

The Dyeing Industry, being a third edition of "Dyeing in Germany and America," by S. H. Higgins.

Aeroplane Timbers: their Structure, Formation, and Mechanical and Commercial Properties, by G. R. Keen.

Industry and Trade: A Study of Industrial Technique and Business Organization; and of their Influences on the Conditions of Various Classes and Nations, by Alfred Marshall.

Automatic Sprinkler Protection (2nd ed.), by G. Dana.

Glass Manufacture (2nd ed.), by W. Rosenhain, D.Sc., F.R.S.

Screw Propellers and Estimation of Power for Propulsion of Ships, also Air-Ship Propellers (2nd ed., Vol. I., Text, Vol. II., Atlas), by Rear-Admiral C. W. Dyson, U.S.N.; from the Kershaw Donation.

Electric Welding and Welding Appliances, by H. Carpmael; from the publishers.

Steamship Coefficients, Speeds and Powers (2nd ed.), by C. F. A. Fyfe; from the publishers.

Industrial Administration: A Series of Lectures; from the publishers.

Weights of Steel Bars, Sections and Plate Tables for Manufacturers and Merchants, and for Use in Offices, Shops, Rod Mills, Tyre Mills, Forges, and Foundries; containing English and Metric Sizes, Weights of Sections in pounds per lineal foot and kilograms per metre long. For Square, Round, Hexagon, Octagon, Three-square, Quarter-octagon, Half-round, Oval Flats, etc.; and Tables for Cogged Bars, for Calculating the Weight of Tyres and Tyre Lumps, Large Forgings, and Casting in Steel; also Table of Factors to find the Weight of other Metals from the Weight of Steel, compiled by T. Stobbs; from the publishers.

Applied Aerodynamics, by L. Bairstow.

Silvanus Phillips Thompson, D.Sc., LL.D., F.R.S.: His Life and Letters, by J. S. Thompson and H. G. Thompson.

Oxy-Acetylene Welding Manual, by L. Campbell, jun.

The Stresses in Hooks and other Curved Beams, by E. S. Andrews.

General Conditions in Electrical and other Engineering Contracts, by W. S. Kennedy, LL.B., with an Introduction by Sir Alex. B. W. Kennedy, LL.D., F.R.S.

Ships' Boats: their Qualities, Construction, Equipment, and Launching Appliances, by E. W. Blocksidge.

The Running and Maintenance of the Marine Diesel Engine: A Reference Book for Marine Motor Engineers and others qualifying as Motor Engineers, giving practical suggestions from Sea Experience, by J. Lamb.

The Deterioration of Structures of Timber, Metal and Concrete Exposed to the Action of Sea-Water: First Report of the Committee of the Institution of Civil Engineers, edited by P. M. Crosthwaite and G. R. Redgrave; from the Committee.

The Reference Library of the Bennett College, Sheffield, from Mr. J. H. Bennett:—

> Beams; Boiler Making; Boilers, Fittings and Design; Draughtsmanship, Vols. I and II; Internal Combustion Engines, Vols. I and II; Marine Engineering; Mechanics; Strength of Materials; Wireless Telegraphy, Vol. I; Workshop Practice.

Pyrometry: A Practical Treatise on the Measurement of High Temperatures (2nd ed.), by C. R. Darling; from the publishers.

Modern History of Warships, Comprising a Discussion of Present Standpoint and Recent War Experiences, for the use of Students of Naval Construction, Naval Constructors, Naval Officers, and others interested in Naval Matters, by W. Hovgaard; from the publishers.

An Account of the Manufactures of the North British Locomotive Co., Ltd., during the period of the War, 1914-1919, with a Short History of the Firms which constituted the Company when formed in 1903; from the Company.

Steam Boiler Construction; Rules of the National Boiler and General Insurance Co., Ltd., with Notes on Material, Construction and Design of Steam Boilers and Similar Vessels, by E. G. Hiller; from the author.

The Design of Screw Propellers with special reference to Their Adaptation for Aircraft, by H. C. Watts, M.B.E.

Applied Aerodynamics, by G. P. Thomson.

Oil Engines: Details and Operation, by L. H. Morrison.

Iron Bacteria, by D. Ellis, D.Sc.

Paper Making and its Machinery: including chapters on the Tub Sizing of Paper, the Coating and Finishing of Art Paper and the Coating of Photographic Paper, by T. W. Chalmers.

The Warner and Swasey Co., 1880-1920; from the Warner and Swasey Co., Cleveland, Ohio.

Bridge and Structural Engineers' Handbook of General Specifications, Formulæ and Data for the Design of Cranes, Bridges, Foundations, and

Workshop Buildings, embodying the Practice of Sir William Arrol and Co., Ltd., by A. Hunter; from the publishers.

Aluminium: its Manufacture, Manipulation and Marketing, by G. Mortimer.

Governors and the Governing of Prime Movers, by W. Trinks; from the publishers.

Motor Lorry Design and Construction: A Handbook of the Latest American Practice, by C. T. Schaefer.

Waterproofing Engineering for Engineers, Architects, Builders, Roofers and Waterproofers, by J. Ross.

Thermodynamics for Engineers, by Sir James Alfred Ewing, K.C.B., D.Sc., F.R.S.

Compressed Air Power: A Treatise on the Development and Transmission of Power by Compressed Air for Engineers and Draughtsmen and for Students of Applied Science, by A. W. and Z. W. Daw.

The Patents, Designs, and Trade Marks Acts, with Notes on all Recent Decisions and Changes in Law and Practice, by H. Fletcher Moulton and J. H. Evans-Jackson.

Hydraulic Machinery: Its Design and Maintenance, by the Hydraulic Engineering Co., Chester; from Mr. C. J. Hobbs.

Industrial Control: The Application to Industry of Direction, Control and Light, by F. M. Lawson; from the author.

The Chemical Analysis of Steel-works' Materials, by F. Ibbotson; from the publishers.

Colloidal Fuel: Composites of Oil and Carbon, by L. W. Bates; from the author.

Metals in Aircraft Construction, by W. Hanby, with a foreword by L. Blin Desbleds.

Foundry Practice: A Text-book for Molders, Students, and Apprentices, by R. H. Palmer (2nd ed.).

Organizing for Work, by H. L. Gantt.

Ozone, by E. K. Rideal, M.B.E., Ph.D.

Practical Sheet Metal Duct Construction: A Treatise in the Construction and Erection of Heating and Ventilating Ducts, by W. Neubecker.

Oil Fuel Burning in Marine Practice: A Manual of Practical Instruction in Oil Fuel Burning, by J. W. M. Sothern.

Cotton Spinning, by W. S. Taggart. Vol. I (6th ed.); Vol. II (5th ed.); Vol. III (5th ed.).

Marconi Dictionary, edited by J. C. H. Macbeth.

Radio Engineering Principles, by H. Lauer and H. L. Brown.

The Propagation of Electric Currents in Telephone and Telegraph Conductors (3rd ed.), by J. A. Fleming, M.A., D.Sc., F.R.S.

Aircraft and Automobile Materials of Construction. Vol. I: Ferrous Materials, by A. W. Judge.

Text-book of Applied Aeronautic Engineering, by H. Woodhouse.

Modern Illuminants and Illuminating Engineering (2nd ed.), by L. Gaster and J. S. Dow.

Structural Drafting and the Design of Details, by C. T. Bishop.

Prospecting for Oil and Gas, by L. S. Panyity.

The Engineering Enquiry: A New Pocket Book for Engineers, for the Assistance of Agents, Contractors, Estimating, Commercial and Technical Correspondents, Merchants, Representatives, and Salesmen, by T. Thompson.

Irrigation Pocket Book: or Facts, Figures, and Formulæ for Irrigation Engineers (3rd ed.), by R. B. Buckley.

Technical Writing, by T. A. Rickard.

British Columbia Timber or Export. Album of 40 photographs with brief particulars; from the Agent-General.

Marine Engineers' Handbook, prepared by a Staff of Specialists and edited by F. W. Sterling; from the editor.

The Fireman's Handbook and Guide to Fuel Economy, a Simple Manual for the Use of Stokers, Furnacemen, Foremen and Others Operating and Controlling Boiler and Furnace Plant, by C. F. Wade; from the author.

Heat Engines: Embracing the Theory, Construction, and Performance of Steam Boilers, Reciprocating Steam Engines, Steam Turbines, and Internal Combustion Engines, by D. A. Low; from the publishers.

Exercises in Graphic Statics with Examples of Its Application to Practical Designing of Constructional Steel Work, Part I (4th ed.): Roof Trusses, Braced Cantilevers, Braced Crane Jibs, &c., by Prof. G. F. Charnock; from the publishers.

Report of the Steel Research Committee founded by the Institution of Automobile Engineers and the Society of Motor Manufacturers and Traders on an Investigation conducted to establish the Mechanical Properties of the British Standard Wrought Automobile Steels (British Engineering Standards Association Report No. 75), and Factors Governing Testing Procedure in connection therewith, October, 1920; from the Committee.

The Dynamics of the Aeroplane, by R. Devillers, translated by W. J. Walker, Ph.D.; from the publishers.

The Coal Question: An Inquiry concerning the Progress of the Nation, and the probable Exhaustion of our Coal-Mines (2nd ed. 1866), by W. S. Jevons; from Mr. Henry Adams.

The History and Description of Fossil Fuel, the Collieries, and Coal Trade of Great Britain (2nd ed. 1844); from Mr. Henry Adams.

The Output Problem, by J. E. Powell.

Mathematics for Engineers: Part I (2nd ed.), Part II, by W. N. Rose.

General Design of Warships, by W. Hovgaard; from the publishers.

Motor and Dynamo Control: Theory and Practice. A Book for the Motor and Switchboard Attendant, and all Engineers who have the Care and Control of Electrical Machines under their Supervision, by W. S. Ibbetson; from the publishers.

Files and Filing, by Ch. Fremont, translated by G. Taylor; from Mr. Harry Brearley.

The Microscope: its Design, Construction, and Applications. A Symposium and General Discussion; from Sir Robert A. Hadfield, Bart.

The Centenary Volume of Charles Griffin and Co., Ltd., Publishers, 1820-1920, with Foreword by Lord Moulton, P.C., G.B.E., K.C.B., F.R.S.; from the publishers.

The Efficiency of Pumps and Ejectors, by E. C. Bowden-Smith.

Carburettors, Vaporisers, and Distributing Valves used in Internal Combustion Engines (2nd ed.), by E. Butler.

Applied Naval Architecture, by W. J. Lovett.

Margarine, by W. Clayton.

Union Textile Fabrication: with Numerous Original Diagrams, Sectional Drawings, and Photographic Reproductions of Spun and Woven Specimens in the Text, by R. Beaumont.

The Manufacture of Sugar from the Cane and Beet, by T. H. P. Heriot.

Geometrical Properties of Ship Girders and Sections; from Lloyd's Register.

OFFICIAL PUBLICATIONS.

British Isles.

Directory of Joint Standing Industrial Councils; Interim Industrial Reconstruction Committees and Trade Boards with Index of Members, January 1920; Report of the Board of Education for the year 1918–1919; Reports for the year 1919 on the Science Museum, and on the Geological Survey and the Museum of Practical Geology; Regulations for Scholarships, Exhibitions, etc., in Science, for the year 1920; from the Board of Education.

Board of Trade Reports on Boiler Explosions; Report to the Secretary of the Board of Trade upon the Working of the Boiler Explosions Acts 1882 and 1890, during the year ending 30 June 1916; Instructions as to the Survey of Life Saving Appliances; Instructions to Surveyors. Bilge Pumping Arrangements in Passenger Steamships (Circular 1615); Standard Conditions for the design and construction of Marine Boilers; Statutory Rules and Orders 1920, No. 976, Merchant Shipping—Wireless Telegraphy; Circular 1624—Instructions to Surveyors; from the Board of Trade.

Annual Report of the Chief Inspector of Factories and Workshops for the year 1919; Safety Pamphlets Nos. 1–5; Report of Proceedings at Industrial Safety Conference; from the Chief Inspector of Factories.

The Commercial Future of Airships, Address by E. M. Maitland to the Royal Society of Arts, 21st April 1920; Half Yearly Report on the Progress of Civil Aviation (1 April 1920–30 Sept. 1920); Professional Notes and Technical Memorandums; from the Air Ministry.

Fourteenth, Fifteenth, Sixteenth and Seventeenth Annual Reports of the Metropolitan Water Board for the years ended 31st March 1917, 1918, 1919 and 1920; from the Metropolitan Water Board.

Fourteenth and Fifteenth Annual Reports of the Meteorological Committee for the years ended 31st March 1919 and 1920; British Meteorological and Magnetic Year Books, 1910, 1916, and 1918; Southport Auxiliary Observatory Annual Report, 1919; Professional Notes; Geophysical Memoirs and Journal; from the Meteorological Office.

Illustrated Official Journal (Patents); Abridgements of Specifications; Subject List of Works on the Textile Industries and Wearing Apparel, etc. (New Series CO 20–CZ); from H.M. Patent Office.

Bulletin No. 4.—Memorandum on Solid Lubricants; Report of the Fuel Research Board for the years 1918-1919; The Peat Resources of Ireland (Special Report No. 2); Report of the Committee of the Privy Council for the year 1919–20; Report of the Food Investigation Board for the year 1919; Report of the Lubricants and Lubrication Inquiry Committee; from the Scientific and Industrial Research Department.

Africa.

Twenty-fifth Annual Report of the Rhodesia Chamber of Mines, 1919; from the Rhodesia Chamber of Mines.

Report of Motor Tractor Ploughing Trials at the Elsenburg School of Agriculture, Mulder's Vlei (C.P.); received from W. S. H. Cleghorne (*A.M.*); Annual Reports of the Secretary for Mines and Industries and the Government Mining Engineer, 31st December 1919; Official Year Book of the Union of South Africa and of Basutoland, Bechuanaland Protectorate and Swaziland—Statistics mainly for the Period 1910–1918; from the Union of South Africa.

Grain Elevators for Union of South Africa—Report by William Littlejohn Philip, O.B.E.; from South African Railways and Harbours.

Municipal Council of Johannesburg—Annual Report of the Town Engineer for the year ended 30th June 1919; from Mr. G. S. Burt Andrews.

Fifteenth Annual Report of the Rand Water Board for the Financial Year ended 31st March 1920; from Mr. William Ingham (Johannesburg).

Argentine Republic.

Apendice and Memoria, Ministerio de Obras Públicas; from the Minister of Public Works.

Australia.

Australian Official Journal of Patents; from the Department of Patents of the Commonwealth of Australia.

Report of the Department of Public Works for the year ended 30th June 1919; Annual Report of the Department of Mines, New South Wales, for the year 1919; The Official Year Book of New South Wales, 1918; Report of the Commissioners, New South Wales Government Railways and Tramways for the year ended 30th June 1920; from the Government of New South Wales.

Port of Sydney—Official Handbook; from the Sydney Harbour Trust Commissioners.

Annual Report of the Under Secretary for Mines for the year 1919; Mining Journal; from the Government of Queensland.

Annual Report of the Chief Inspector of Machinery and Chairman of the Board of Examiners for Engine-drivers for the year ended 31st December 1918, with Statistics; Report on the working of the Government Railways and Tramways for the year ended 30th June 1919; Report of the Department of Mines for the year 1918; from the Department of Mines, Western Australia.

Canada.

Twenty-ninth Annual Report of the Ontario Department of Mines, Vol. XXIX, Parts III and V; also various Bulletins, Memoirs and Reports of the Department of Mines, Ottawa; from the Government of Canada.

Water Powers of British Columbia, by Arthur V. White, Ottawa, 1919; from the Commission of Conservation, Ottawa.

China.

List of the Chinese Lighthouses, Light-Vessels, Buoys and Beacons, 1920; from the Inspector-General of Chinese Customs.

India.

Classified List of State Railway Establishment and distribution Return of Establishment of all Railways, 31st December 1919; Classified List of Establishment to 31st December 1919; from the Registrar.

Records of the Survey of India, Vol. X and XIII: Annual Reports of Parties and Officers, 1915-16, 1917-18; prepared under the direction of Colonel Sir S. G. Burrard, K.C.S.I., and Colonel C. H. D. Ryder, C.I.E., D.S.O. (Surveyor-General of India); Railways in India—Administration Report for the year 1918-19, Vol. I (Report), Vol. II (Appendices); Technical Papers; from the Government of India.

New Zealand.

Journal of Science and Technology; from the Board of Science and Art.

United States.

Fourteenth Annual Report of the Board of Water Supply of the City of New York, 31st December 1919; from the Board of Water Supply.

National Research Council, Bulletin, Vol. I, No. 1; from the National Academy of Science.

Bureau of Standards, Scientific and Technologic Papers; from the Department of Commerce.

Professional Papers, Water-Supply Papers, Bulletins and various Pamphlets; from the U.S. Geological Survey.

Official Gazette; from the United States Patent Office.

PAMPHLETS.

Apprentice Training by the British Thomson-Houston Co., Ltd., Rugby; from the Company.

A New Prime Mover of High Efficiency and British Origin—The Still Engine, by F. E. D. Acland; from Mr. H. A. D. Acland.

Central Electric Stations in Canada, Part II—Directory, by J. T. Johnston; from the author.

Foundations for Machinery, by Henry Adams; from the author.

Report of Committee on Registration of Engineers; from the Engineering Council, N.Y.

Report of Committee on Classification and Compensation of Engineers; from the Engineering Council, N.Y.

Examples in Heat and Heat Engines, by T. Peel.

Photo-Elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members, by Prof. E. G. Coker, D.Sc., F.R.S., K. C. Chakko, and Y. Satake; from Prof. E. G. Coker, D.Sc., F.R.S.

Motor Transport in the Sudan, by J. Rhodes; from the author.

Some Sanitary Installations, and an Experiment, in Patna, by F. C. Temple; from the author.

Motor Craft for Shallow and Obstructed Waters, by J. H. W. Gill; from the author.

Presidential Address to the Inst. C.E. Manchester Association of Students, by J. P. Bedson; from the author.

Gas in Relation to Increased Output and National Economy, by H. M. Thornton; from the author.

Pieux et Sonnettes, by E. Noë and L. Troch; from the publishers.

Naval Engineering: Four Historical Lectures, with blue prints, by E. C. Smith; from the author.

Fine Measurement in Engineering Workshops, a Lecture by V. I. N. Williams; from Sir W. G. Armstrong, Whitworth and Co.

Résistance des Matériaux et Élasticité, by G. Pigeaud; from the author.

Utilisation des Vapeurs d'Échappement dans les Houillères en vue de la Production d'Énergie Électrique, by A. Barjou; from the publishers.

Notes on Operating a By-Product Producer Gas Plant for Power and Heating, by W. H. Patchell; from the author.

Calculating Machines, by Dr. E. M. Horsburgh; from the author.

Metallographic Phenomena observed in Amalgams, by A. W. Gray; from the author.

The Most Suitable Steels for Automobile Parts, by Dr. W. H. Hatfield; from the author.

Development of the Cold Storage of the Port of London Authority, by H. J. Deane; from the author.

Dorman Wave Power Tools; from the publishers.

The Hele-Shaw Hydraulic (Oil) Clutch; from the publishers.

Exact Data on the Running of Steam Boiler Plants, by D. Brownlie:—No. 1, Economisers. No. 2, The Performance of Colliery Steam Boiler Plants and the Saving to be obtained by their Reorganization. No. 3, The Amount of Steam Used by Steam Jets. Coal Saving by the Scientific Control of Steam Boiler Plants; from Messrs. Brownlie and Green, Ltd.

Presidential Address to the British Commercial Gas Association, 1920, by Sir Robert A. Hadfield, Bart., F.R.S., D.Sc., D.Met.; from the author.

Our Coal and our Coal-Pits: The People in Them and the Scenes around Them (in 2 parts), by "A Traveller Underground," (1853); from Mr. Henry Adams.

The Electricity (Supply) Act, 1919: with Notes, by W. S. Kennedy, LL.B.

Engineers Unite: High Spots in the Washington Organizing Conference of the Federated American Engineering Societies, June 3 and 4, as Reported and Interpreted by the Editors of the Technical Press; from the publishers.

Shock Tests and Their Standardization: Including the Effect of High Velocities on Impact up to 2,870 feet per second, by Sir Robert A. Hadfield, Bart., F.R.S., and S. A. Main; from Sir Robert A. Hadfield, Bart., F.R.S.

Baldwin Locomotive Works: Record No. 95.

DIRECTORIES, ANNUALS, REFERENCE INDEXES, &c.

The Aviation Pocket-Book for 1919–20: a Compendium of Modern Practice and a Collection of Useful Notes, Formulæ, Rules, Tables, and Data relating to Aeronautics, by R. B. Matthews.

Directory of Directors, 1920.

The "Electrician" Electrical Trades' Directory and Handbook, 1920.

The Engineering Index, monthly issues for Feb., Aug., Sept., Oct. and Nov. 1920.

The Engineer's Year Book, 1920, by H. R. Kempe; from the proprietors.

Garcke's Manual of Electrical Undertakings, 1920.

The Jews' Who's Who: Israelite Finance, its Sinister Influence; from the publishers.

Kelly's Directory of the Engineers, Iron, Metal, and Electrical Trades, 1920.

Kelly's Directory of Merchants, Manufacturers, and Shippers of the World, Vols. I and II, 1920.

Kelly's Post Office London Directory, 1921.

Lloyd's Register of Shipping—Report of the Society's Operations during the year 1919–1920; from Lloyd's Register.

London Master Builders' Association, Handbook and Diary, 1920.

Official Year Book of the Scientific and Learned Societies, 1919.

"Practical Engineer" Electrical Pocket Book and Diary, 1920; from the publishers.

"The Practical Engineer" Mechanical Pocket Book and Diary for 1920; from the publishers.

The Railway Year Book for 1920: The Whitaker of the Railway World.

Revue de L'Ingénieur et Index Technique, Bruxelles, Vol. XXVI, Nos. 1–6, Vol. XXVII, Nos. 1–6.

Ryland's Colliery, Iron, Steel, Tin-Plate, Engineering and allied Trades' Directory, 1920.

Stock Exchange Year Book, 1920.

Whitaker's Almanack, 1921; from the British Electric Transformer Co.

Who's Who, 1921.

Who's Who in Engineering, 1920; edited by J. E. Sears, C.B.E.

Year Book of Wireless Telegraphy and Telephony, 1920; from Marconi's Wireless Telegraph Co.

CALENDARS AND COLLEGE REPORTS

(from the respective Authorities).

British Isles.

University of Birmingham; Calendar, 1919–20.
City of Bradford Technical College; Calendar, 1920–21.
University College of South Wales and Monmouthshire; Prospectus, 1920–21.
Edinburgh University; Calendar, 1920–21.
Glasgow University; Calendar, 1920–21.
University of Leeds; Fifteenth Report, 1918–19, and Calendar, 1920–21.
University of Liverpool; Calendar, 1920–21.
City and Guilds of London Institute; "The Central."
Imperial College of Science and Technology; Calendar, 1920–21.
King's College, London; Calendar, 1920–21.
The South Western Polytechnic; Prospectus, 1920–21.
University College, London; Calendar, 1920–21.
The Technical College, Loughborough; Calendar, 1920–21.
Victoria University of Manchester; Calendar, 1920–21.
University College of Sheffield; Calendar, 1920–21.

Africa.

University of Cape Town, Engineering and Scientific Society; Calendar, 1920.

Australia.

South Australian School of Mines and Industries; Annual Report, 1919.

China.

University of Hongkong; Calendar, 1919–20.

Japan.

Imperial University of Kyushu; Vol. II, No. 1.
Imperial University of Tôhoku; Science and Technology Reports.
Imperial University of Tokyo; Journal.

United States.

Worcester Polytechnic Institute; Catalogue, 1919–20.

DRAWINGS.

Drawings of Steam Engines and Pumps, by Messrs. Carrett, Marshall and Co., (1855); from Mr. Harold Beckwith.
Bow Protection and H. S. M. S. Monographs, with 23 Sketches.
Paravanes, 53 Drawings.

PERIODICAL PUBLICATIONS OF SOCIETIES, &c.

(*Those marked * are bound for preservation in the Library.*)

British Isles.

Aëronautical Journal.

*Automobile Engineers, Institution of; Proceedings.

Birmingham Metallurgical Society; Journal.

*British Association for the Advancement of Science; Report.

British Engineering Standards Association; Reports, etc.

British Engineers' Association; British Engineers' Export Journal.

Chartered Accountants, Institute of, List of Members, 1921.

Chemical Industry, Society of; Journal.

Chemical Society; List of Officers and Fellows, 1920.

Chemistry of Great Britain and Ireland, Institute of; Proceedings.

*Civil Engineers, The Institution of; Some Aspects of Metropolitan Road and Rail Transport, Lecture by H. H. Jordan; Subject-Index, Vols. CLXXI. to CCIV.; Minutes of Proceedings; and List of Members, 1920.

Cleveland Institution of Engineers, Middlesbrough; Proceedings.

Cold Storage and Ice Association; Proceedings.

Conjoint Board of Scientific Societies; Diary.

*Electrical Engineers, Institution of; Journal.

Engineers-in-Charge, The Association of; Proceedings.

*Engineers, Society of; Transactions.

*Engineers and Shipbuilders in Scotland, Institution of; Transactions.

*Gas Engineers, Institution of; Transactions.

*Heating and Ventilating Engineers, Institution of; Proceedings.

*Iron and Steel Institute; Journal.

*Junior Institution of Engineers; Transactions.

*Liverpool Engineering Society; Transactions.

*Manchester Association of Engineers; Transactions.

Manchester Steam Users' Association; Memorandum by Chief Engineer, 1918–19, and Annual Report, 1919.

*Marine Engineers, Institute of; Transactions.

*Metals, Institute of; Journal.

Mining Engineers, Institution of; Transactions.

*Mining and Metallurgy, Institution of; Transactions and List of Members, 1920.

*Municipal and County Engineers, Institution of; Journal.

National Physical Laboratory; Report for the year 1919, and Supplementary Report for the year 1918, and Scheme of work for the year 1919–20, and Collected Researches, Vol. XIV, 1920.

*Naval Architects, Institution of; Transactions and List of Members, 1920.
*North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne; Transactions.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne; Transactions and Annual Report, 1918–19.
Patent Agents, Chartered Institute of; Transactions.
Permanent Way Institution; Journal.
Petroleum Technologists, Institution of; Journal.
Physical Society of London; Proceedings.
Post Office Electrical Engineers; Journal.
Radcliffe Library, Oxford; Catalogue of Additions during 1919.
*Royal Agricultural Society of England; Journal.
Royal Artillery Institution, Woolwich; Journal.
Royal Cornwall Polytechnic Society; Report.
Royal Dublin Society; Scientific and Economic Proceedings.
Royal Institute of British Architects; Journal and Calendar.
Royal Microscopical Society; Journal.
Royal Philosophical Society of Glasgow; Proceedings.
*Royal Sanitary Institute; Journal.
Royal Society of Arts; Journal.
Royal Society of Edinburgh; Proceedings.
Royal Society of London; Proceedings (A), Year Book, 1920, and Philosophical Transactions.
Royal United Service Institution; Journal.
*Science Abstracts—Physics and Electrical Engineering.
*South Wales Institute of Engineers, Cardiff; Proceedings.
*Staffordshire Iron and Steel Institute; Proceedings.
Surveyors' Institution; Transactions.
Tramways and Light Railways Association; Journal.
Transport, Institute of; Journal.
*Water Engineers, Institution of; Transactions.
West of Scotland Iron and Steel Institute, Glasgow; Journal.

Other Countries (alphabetical).

Africa.

Chemical, Metallurgical and Mining Society of South Africa, Johannesburg; Journal.
South African Institution of Engineers, Johannesburg; Journal.

Australia.

Australasian Institute of Mining and Metallurgy; Proceedings.
Royal Society of New South Wales; Journal.
Victorian Institute of Surveyors; Transactions and Proceedings.

Austria.

Zeitschrift des Oesterr. Ingenieur-u. Architekten-Vereines.

Belgium.

Académie Royale de Belgique; Bulletins and Annuaire, 1915–1919.
International Railway Congress, Bulletin. (English Edition.)
Association des Ingénieurs sortis des Écoles spéciales de Gand, Annales.
Association des Ingénieurs sortis des Écoles de Liège.

Canada.

Engineering Institute of Canada; Journal and Transactions.
Revue Trimestrielle Canadienne.
Royal Society of Canada, Ottawa; Proceedings and Transactions.

France.

Académie des Sciences, Paris; Comptes Rendus des Séances.
Annales des Mines, Paris.
Annales des Ponts et Chaussées, Paris.
*Association française pour l'Avancement des Sciences; Conferences, 1918-1920, and Bulletin.
Association française du Froid; "Le Froid."
Associations de Propriétaires d'appareils à vapeur, Bulletin.
Société de Chimie Industrielle, Paris; "Chimie et Industrie."
Société Industrielle de Mulhouse; Bulletin.
Société Industrielle de Rouen; Bulletin.
Société d'Encouragement pour l'Industrie Nationale, Paris; Bulletin.
Société Industrielle du Nord de la France; Bulletin.
Société des Ingénieurs Civils de France, Paris; Bulletin.

Germany.

Stahl und Eisen, Düsseldorf.
Zeitschrift des Bayerischen Revisions-Vereins, Munich.
Zeitschrift des Vereines deutscher Ingenieure, Berlin.

Holland.

Koninklijk Instituut van Ingenieures, 's-Gravenhage; Register, 1918-1919.

India.

*Committee of the Locomotive, Carriage and Wagon Superintendents of Indian Railways, Madras; Proceedings.

Italy.

Associazione fra gli Utenti di Caldaie a Vapore nelle Provincie; Napolitane Rapportoi Annuali, 1915–1919.
Associazione Elettrotecnica Italiana, "L'Elettrotecnica," Milan.
Rivista Tecnica delle Ferrovie Italiane, Roma.
Società degli Ingegneri e degli Architetti Italiani, Roma; Annali d' Ingegneria.

Japan.

Society of Mechanical Engineers, Tokyo; Journal.

Norway.

Teknisk Ukeblad, Christiania.

Sweden.

Svenska Teknologföreningen, Stockholm.
University of Upsala; Geological Institution; Bulletin.

United States.

American Institute of Electrical Engineers, New York; Year-Book, 1920, and Journal and Transactions.
American Philosophical Society, Philadelphia; Proceedings and Transactions.
*American Society of Civil Engineers, New York; Proceedings.
*American Society of Mechanical Engineers, New York; Journal, Transactions and Year-Book, 1920.
American Society of Naval Engineers, Washington; Journal.
American Society of Refrigerating Engineers, New York; Journal.
Engineers' Club, Philadelphia; Proceedings.
Engineers' Society of Western Pennsylvania, Pittsburgh; Proceedings.
Franklin Institute, Philadelphia; Journal.
John Crerar Library, Chicago; Twenty-fifth Annual Report, 1919.
*Library of Congress, Washington; Report, 1919.
Library of Stone and Webster, Boston; Journal.
Michigan Technic.
National Academy of Sciences, Washington; Proceedings.
New York Railroad Club; Official Proceedings.
St. Louis Railway Club; Official Proceedings.
Smithsonian Institution; Annual Report, 1917.

Stevens' Indicator.
*Traveling Engineers' Association; Proceedings.
United States Artillery, Fort Monroe; Journal.

The following Duplicates have been received for Loan Purposes.

American Society of Mechanical Engineers; Journal and Transactions.
Automobile Engineers, Institution of; Proceedings.
British Association; Reports, 1910-18; from Dr. W. Cawthorne Unwin, F.R.S.
Civil Engineers, Institution of; Minutes of Proceedings.
Electrical Engineers, Institution of; Journal.
Engineers and Shipbuilders in Scotland, Institution of; Transactions.
Iron and Steel Institute; Journal.
Liverpool Engineering Society; Transactions.
Manchester Association of Engineers; Transactions.
Metals, Institute of; Journal.
Mining and Metallurgy, Institution of; Bulletin.
North-East Coast Institution of Engineers and Shipbuilders; Transactions.
Society of Engineers; Bound Vols. 1880 1891, and 1892 1906; received from Mr. H. C. Walker.
South Wales Institute of Engineers; Proceedings.

OTHER PERIODICALS.

*(Those marked * are bound for preservation in the Library.)*

British Isles.

Aeronautics.
Aeroplane.
Arms and Explosives.
Autocar.
Automobile Engineer.
Auto-motor Journal.
Beama Journal.
*British Printer, Feb. 1910 to Mar. 1918; from Mr. L. A. Legros, O.B.E.
Builder.
Cheap Steam.
Civil Engineering.
Coal and Iron and By-Products Journal.
Cold Storage and Produce Review.
Colliery Guardian.
Commercial Motor.
Concrete and Constructional Engineering.
Domestic Engineering.
Electrical Industries and Investments.
Electrical Review.
Electrical Times.
*Electrician.

*Engineer.
Engineer and Iron Trades Advertiser.
*Engineering.
Engineering and Industrial Management.
Engineering Production.
Engineering Review.
Ferro-Concrete.
Fishing Gazette.
Flight.
Foundry Trade Journal and Pattern-Maker.
Gas Journal.
Gas and Oil Power.
Hardware Trade Journal.
Ice and Cold Storage.
Illuminating Engineer.
Irish Builder and Engineer.
Iron and Coal Trades Review.
Iron and Steel Trades Journal and Iron Trade Circular.
Ironmonger.
Junior Mechanics and Electricity.
Kahncrete Engineering.
Locomotive Magazine.
London and China Express, with supplement.
London County Council Gazette.
Machine-Tool Review.
*Machinery.
Marine Engineer.
Mechanical World.
Mining Journal.
Model Engineer and Electrician.
Modern Transport.
Motor Boat.
Motor Ship.
Motor Traction.
*Nature.
Philosophical Magazine and Journal of Science.
Practical Engineer.
Quarry.
Railway Gazette.
Shipbuilder.
Shipbuilding and Shipping Record.
South African Engineering.
Steamship.
Syren and Shipping Illustrated.
Textile Recorder.
Times, and Engineering Supplement.
Tramway and Railway World.
Water and Water Engineering.
Wireless World.

Other Countries (alphabetical).

Austria.

Casopis Československých Inženýrův a Architektův.

Belgium.

Revue Universelle des Mines.

Canada.

Canadian Machinery and Manufacturing News.

France.

Bulletin Technique du Bureau Veritas.
Génie Civil.
Revue Générale des Chemins de Fer.

Germany.

*Deutscher Buch- und Steindrucker, Oct. 1909 to July 1914 (lacking Sept. and Dec. 1913); from Mr. L. A. Legros, O.B.E.
Dinglers Polytechnisches Journal.
Elektrotechnische Zeitschrift.
Giesserei Zeitung.
Glaser's Annalen.
Glückauf.
Organ für die Fortschritte des Eisenbahnwesens.

Holland.

De Ingenieur.

Italy.

Giornale del Genio Civile.

Switzerland.

Schweizerische Bauzeitung.

United States.

*American Machinist.
Blast Furnace and Steel Plant.
Brotherhood of Locomotive Firemen and Enginemen's Magazine.
Electric Railway Journal.
Electrical Review.
Electrical World.
*Engineering News-Record.
Foundry.
*Inland Printer, Oct. 1909 to Mar. 1912 and April 1916 to Mar. 1920; from Mr. L. A. Legros, O.B.E.
Machinery.
Railway and Locomotive Engineering.
Railway Mechanical Engineer.
Railway Review.
Scientific American with Supplement.

A SMALL BALL-HARDNESS TESTING-MACHINE.

BY H. MOORE,* O.B.E., B.Sc., F.I.C., OF THE RESEARCH DEPARTMENT, WOOLWICH.

[*Selected for Publication.*]

It had been intended that Mr. R. Mather, who was associated with the Author in the design and development of the machines to be described, should be a co-author of this Paper, but owing to Mr. Mather's absence in India, this has not been possible.

The Brinell ball-hardness test, as commonly applied, employs a ball of 10 mm. diameter and a load of 3,000 kg., although other balls and loads are not infrequently used. The limits of thickness and other dimensions of the specimen, relative to the size of the impression, within which correct results are given by the ball-hardness test, were studied by the Author † some years ago. It was found that generally the dimensions of the test-piece had no appreciable effect on the hardness number obtained, provided that the depth of the impression did not exceed one-seventh of the thickness of the test-piece, and that the diameter of the impression did not exceed one-half of the distance of the edge of the impression from the edge of the test-piece. In some cases it is possible to determine accurately the Brinell hardness of specimens which do not quite come within these limits, and the form of the specimen, and still more its method of support, are factors affecting the limiting conditions. In practice, however, the use of the ball of 10 mm. diameter is limited to specimens not much less than one-tenth of an inch in thickness and half an inch in width, and these dimensions are not sufficient in all cases.

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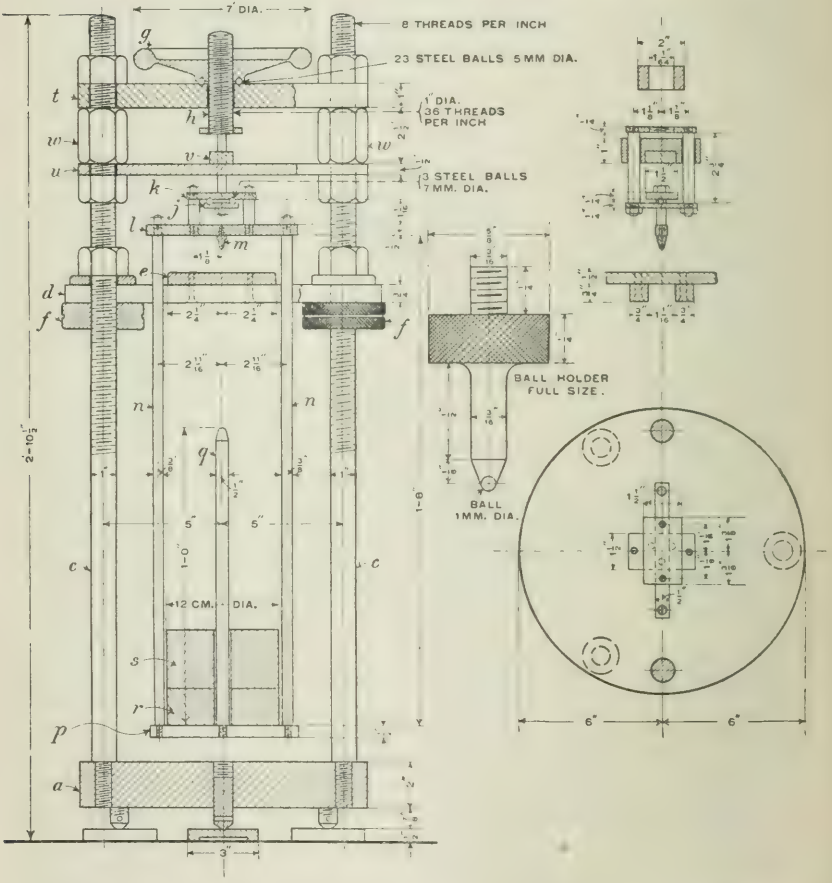
* Awarded a Grant of £10 from the Sir Robert Hadfield Prize Fund.

† Investigations on the Brinell Method of Determining Hardness. H. Moore. International Association for Testing Materials 5th Congress (Copenhagen), 1909.

In 1913 the necessity arose for the accurate determination of the hardness of the walls of small-arm cartridge-cases at different positions along their length. The thickness of wall is quite insufficient for the application of the usual Brinell test, diminishing in some

FIG. 1.—*Small Ball-Hardness Testing-Machine.*

Capacity 100 kg. Shown with ball of 1 mm. diameter and load of 10 kg.



cases to about one-hundredth of an inch near the shoulder. Accordingly, a machine was designed and constructed for applying a load of 10 kg. with a ball of 1 mm. diameter. It was evident that such a machine would have many uses in the determination of the hardness of objects too thin or narrow for testing in the usual way, and for the detailed exploration of the hardness of larger objects. It was therefore designed to permit of great latitude in the dimensions of the test-specimen, of the use of various sizes of ball and of loads from 5 to 100 kg.

For the small loads required, the use of a dead-load offered the important advantages of simplicity, invariable accuracy, and the complete elimination of all frictional effects, while the operation of the machine and the moving of the weights could easily be effected by hand. The machine is extremely simple in principle, consisting of a suspended weight with means for applying the load to the ball and removing it, the test-specimen being suitably supported.

Fig. 2, Plate 1, shows the general appearance of the machine, while the dimensioned drawing, Fig. 1, shows the constructional details. The machine consists essentially of a stirrup carrying the load, a table to support the specimen, and suitable mechanism for lowering the stirrup, so that the ball (carried in the ball-holder attached to the under side of the upper cross-head of the stirrup) comes into contact with the specimen. By reversing the lowering movement, the stirrup is raised.

In the drawing, *a* is the heavy circular base-plate. The level of the base is adjusted by three levelling screws, each of which seats in a circular plate resting on a bench or other convenient surface; *c.c.* are two columns screwed along the upper part of their length, and carrying by means of adjustable nuts all the mechanism. Resting on the adjusting nuts *f* are two cross-bars *d* carrying the table *e*, a plate 4½ inches square. To the table are attached various fittings designed to facilitate the exact centering of test-pieces, such as the middle portions of cartridge-cases carried on mandrels. The cross-head *t* rests on the distance nuts *w*, and carries a hand-wheel *g* on ball-bearings. The hand-wheel is threaded to take the lifting screw *h*, which has a fine pitch. Rotation of the hand-wheel *g* in one direction or the other raises or lowers the lifting screw which passes without contact through the plain hole in the cross-head *t*. The small suspension stirrup formed by two cross-plates and two vertical rods is rigidly attached to the lower end of the lifting screw. The two rods slide with small clearance in two holes in the guide-block *v*, which is fixed, being carried by the cross-plate *u*. The bottom suspension plate *j* of the small lifting stirrup carries three steel balls equidistant from each other and from the axis of the machine, in three recesses. Resting on the three steel balls is the top suspension-plate *k* of the load-carrying stirrup; this top suspension-plate has three recesses similar to those in the bottom suspension-plate *j*. Suspended from *k* by short rods is *l*, the cross-bar of the load-carrying stirrup. The ball-holder *m* is screwed into the centre of the lower surface of this cross-bar, from which are suspended two vertical rods *n* passing between and quite free from the bars *d*, and carrying the bottom plate *p*, on which are placed the weights *r* and *s*. The weights are cylindrical, with a central hole for the guiding-rod *q*, attached to the bottom plate *p*. The total weight of all the suspended portion (stirrup, etc.), plus the weight *r*, is 5 kg.; *s* is a 5-kg. weight, the total load given by the machine as drawn being 10 kg.

The method of suspending the stirrup on three balls was adopted, since it prevents either rotation or swing of the load-carrying stirrup, and makes both the release at the moment of loading and the uptake at the moment of unloading perfectly clean and frictionless. The movement of the test-ball is purely vertical, no rotational or side movement being possible. This result is achieved without any guiding of the suspended load during loading; such guiding is always a possible source of friction.

The machine is constructed throughout of steel. A test-ball of any desired diameter may be used. The strength of the machine permits a maximum load of 100 kg., and a minimum load of 2 kg. may be used. An accuracy of load of 0·02 per cent is easily attained, but it is rarely that such a degree of accuracy is needed. The table and cross-heads have a wide range of adjustment of position in the vertical direction, thus permitting the testing of specimens of very different sizes. The machine is portable and intended to stand on a bench when in use.

Special fittings to support specimens of various forms are much used on this machine. Comparatively thin tubes may be tested without internal support, being held in a V-block, but a thinner tube may be carried on a mandrel supported at each end. An overhanging part may be tested by clamping the article to the table. A special fitting for testing sections of small-arm cartridge cases is shown in Fig. 3, Plate 1, but it is now possible to dispense with cutting the case and to test the complete round without removing bullet, charge, or cap. The cartridge may be fired afterwards.

Figs. 4 and 5, Plates 1–2, show two machines of similar type constructed a little later. The machine shown in Fig. 4 has a smaller range of load and gives less latitude in dimensions of test-piece than the original machine ; a ball of 0·8 mm. in diameter with a load of 6·4 kg. is commonly used on this machine. Fig. 5 shows a machine designed for testing Q.F. cartridge-cases of any size up to the largest used in the British services, but is also suitable for testing other objects (especially large thin-walled articles) of a great variety of shape and dimension. This machine commonly employs balls of 2 and 5 mm. diameter, and has a range of loading of 20 to 250 kg. The back-plate on which this machine is mounted is bolted to a wall, in order to provide for the necessary height and length of large articles without having a special stand.

The accurate measurement of the small impressions obtained when small balls are employed is essential in the use of the machines described. A certain degree of smoothness or polish on the specimen is necessary, and a reasonably good polish much facilitates the measurement. Vertical illumination is necessary for the smaller impressions. Several forms of measuring microscope have been employed by the Author, such as those made by Messrs. R. and J. Beck and the Cambridge Scientific Instrument Co., reading to 0·001 mm. Fig. 6, Plate 2, shows a convenient and accurate microscope specially designed for the purpose. A large solid square stage carries a pillar on which a microscope tube is mounted and provided with the usual vertical rack and pinion focussing movement; a fine adjustment motion is not necessary. A prism type vertical illuminator, to which is fixed, about 1 inch from the prism, a small electric bulb supplied with current by a small accumulator or dry cell, provides a suitable and ample illumination. The objective has a nominal focal length of 1 inch. The eye-piece is a filar micrometer eye-piece, Ramsden system, of the standard type ; that fitted to the instrument illustrated is a Bausch and Lomb ocular. The tube length has been adjusted, for the objective chosen, to give a magnification of exactly 10 diameters in the plane of the eye-piece scale. As the eye-piece magnifies by 12·5, the total magnification is 125. The accuracy of measurement possible with filar micrometer eye-pieces of good construction is remarkably good ; agreement to 0·0001 mm. is not uncommon, though an accuracy of 0·001 mm. is sufficiently good. Instead of a micrometer eye-piece of the filar type, one with a fine graticule may be used.

A feature of the larger machine, illustrated in Fig. 5, is the microscope attached to the frame of the machine. The table supporting the test-specimen slides on rails. After the impression is made and the load removed, the table with specimen is moved along the rails till the impression is under the microscope and the reading is taken. This saves much handling of bulky articles, such as large Q.F. cartridge-cases. The cartridge-case may be tested either on the base or on the wall, suitable fittings being provided for supporting the case rigidly in either position.

Instances, in which the accurate measurement of hardness by the use of a small ball would be helpful, will occur to all who are interested in the hardness of metallic parts. In the Research Department, Woolwich, the machines have been used on specimens of a great variety of material, form, and dimension. By the use of the original machine described, it became possible to lay down limits of hardness (varying in different positions along the wall) within which small-arm cartridge-cases give the highest serviceability and the greatest freedom from failures and defects, so far as these result from unsuitable hardness. The impressions are so small as to be scarcely perceptible to the eye, and tests may be made on parts of delicate mechanisms without injury to the part tested.

The thickness of the specimen need not exceed one-hundredth of an inch. Thin wire and phosphor-bronze hair-springs have been tested. Cutlery blades, however thin, may be tested; the Author has been interested to note Dr. W. H. Hatfield's recent application * of balls of 2·4 mm. diameter in the testing of cutlery, especially stainless blades.

It is possible to determine the hardness of an object near the working edge or surface; the hardness of a cutting tool may be measured at a point close to the cutting edge and at many points on the same tool as a test of uniformity. The use of small balls (1 mm. in diameter) has proved useful in the examination of parts which have been locally hardened, or which vary in hardness from point to point from any other cause. The greater hardness in the centre of a segregated steel rod is readily measured and delimited.

One of the most interesting applications of this microscopic Brinell test is in the exploration of strain-hardening. The degree of hardening by plastic deformation of metals generally increases with increasing amounts of permanent strain. If a metal object, originally of uniform hardness, is unequally strained, the distribution of strain will usually be indicated by differences in hardness from point to point. Fig. 7, Plate 2, illustrates a broken tensile test-piece, sectioned through its axis, polished on this surface and submitted to the 1-mm. ball-hardness test at small intervals over the surface. The variation in hardness is very considerable. In this instance the strain was produced intentionally, but cases have been examined in which the progress of overstraining, resulting in the failure of a structural part, has left a clear record in the variation of hardness throughout the region affected. This method of strain-exploration by hardness tests with a small ball has been extensively developed in the Research Department, Woolwich, by Mr. R. H. Greaves, who will, the Author hopes, publish some of the interesting results he has obtained.

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* "Cutlery; Stainless and Otherwise." W. H. Hatfield, Sheffield Cutlery Trades' Technical Society, 1919.

In connexion with strain-hardening, the utility of the small-ball test for studying the hardening caused by cold-working operations, and the softening brought about by the intermediate annealings which are customarily applied, may be mentioned. In wire-drawing, tube-drawing, the drawing of hollow brass articles, the spinning of articles from sheet, and the cold-rolling of strip of steel, copper alloys, etc., the articles both in intermediate and final form are frequently too thin for the usual test. By a study of the hardness, the correct amount of reduction at each draw or other cold-working operation and the best temperature and time of annealing may be established in many cases. The variations in hardness produced in articles of complex form (for example, small-arm cartridge cases) by variations in amount of cold work from point to point are readily determined. The difference in hardness along a diameter of a section of cold-drawn steel-rod may be measured. For studying the annealing of brass, actual hardness tests have been found to give much information additional to that yielded by the usual microscopic examination. The determination of the treatment which would remove injurious internal stress from 70 : 30 brass without adverse effect on mechanical properties was facilitated by the use of the small ball machine.*

There has been some difficulty in obtaining balls of 1 mm. diameter, but the Author has reason to expect that this will not continue. Balls of $\frac{3}{64}$ inch diameter are readily obtainable and are conveniently regarded as of 1·2 mm. diameter (for use with millimetre tables showing the hardness number for a given load and given ball) without introducing any appreciable error.

The relation of the hardness numbers obtained with small balls to those given by the usual methods is an important point. The laws governing the effects of variations in load, ball diameter, and angle of impression, were thoroughly established by E. Meyer † and have been confirmed by later workers. References to the chief work on this subject will be found in a recent Paper by T. Baker and T. F. Russell,* which contains further valuable results. In the discussion on that Paper the Author of the present Paper pointed out that Meyer's two equations may be expressed in the form :—

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* The Removal of Internal Stress in 70 : 30 Brass by Low Temperature Annealing. H. Moore and S. Beckinsale. Journal Inst. Metals, vol. xxiii, No. 1, 1920, page 225.

† Hardness Testing and Hardness. E. Meyer. Zeits. des Ver. deutscher Ing., vol. lii, 1908, page 645.

$$L = \frac{k\ d^n}{D^{n-2}}$$

in which L = load,
d = diameter of impression,
D = diameter of ball,

while k and n are two independent constants expressing properties of the material, and are unaffected by variations in L, d, or D.

Contained in this equation is the law of geometrical similarity, which holds for the ball-hardness test on material of uniform hardness and requires that, with balls of different diameter, geometrically similar impressions are produced by constant mean loads per unit area.

For practical purposes, it is only necessary to employ loads proportional to the square of the ball diameter to obtain the same Brinell hardness numbers with different sized balls. In the following Table the loads commonly employed with balls of the various sizes used are shown. The loads in any one column will give the same Brinell number when used with their respective balls (*see* page 60).

As is well known, different loads with balls of the same diameter will give, in tests on the same uniform material, Brinell hardness numbers which differ to a greater or smaller degree. For a fuller consideration of this question reference should be made to the Papers by Meyer (*loc. cit.*) and other Authors already indicated. Should the Ludwik cone test, with its important theoretical advantage of a hardness number independent of the load, replace the Brinell ball test, the machine described is equally suitable for that test. In the Author's opinion, the ball is likely to be retained because of its practical convenience and its permanence of form.

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* Note on the Ball Test. T. Baker and T. F. Russell. Journal Iron and Steel Inst., vol. ci, No. 1, 1920, page 341.

It should be borne in mind that, since the volume of material actually affected by the test is proportional to the cube of the diameter of the ball, a very much smaller volume is tested by a ball of say 1 mm. diameter than by a ball of 10 mm. diameter. In consequence of this, local differences (due for instance to variations in hardness of different constituents in a coarse microstructure) which have little or no effect when testing with a 10 mm. ball, may attain prominence when a small ball is used. Frequently the knowledge of such variations is useful. Severe machining operations are capable of hardening metallic surfaces. In preparing surfaces of soft materials for testing with a small ball, more care is necessary to avoid surface hardening than when a large ball is to be used, because of the greater effect of a harder skin on a small impression than on a deep one. The degree of accuracy attained in testing with a small ball is quite comparable with that obtained in the Brinell test as usually applied. An accuracy of about 1 per cent is readily attained.

Diam. of ball.	Load.		
mm.	kg.	kg.	kg.
0·8	6·4	19·2	32
1	10	30	50
1·2	14·4	43·2	72
2	40	120	200
5	250	750	1,250
10	1,000	3,000	5,000
	Suitable for fairly soft materials. (e.g., copper, brass.)	Suitable for moderately hard materials. (e.g., steel not fully hardened.)	Suitable for the hardest materials tested. (e.g., hardened steel.)

The original machine described, which has been in constant use in the Research Department, Woolwich, since 1913, was designed with a view to the construction of one machine only, and it will be obvious to engineers that, for production in number, some simplification and modification of details might be made with advantage, as in the use of castings instead of parts machined from bar and plate. A machine modified in this way is being made by Messrs. Alfred Herbert, Ltd., and the Author would like to acknowledge the interest taken in the machine by Mr. P. V. Vernon, O.B.E., of that firm, and the suggestions he has made.

In conclusion, the Author wishes to express his regret that Mr. R. Mather has not been associated with him in the authorship of this Paper, as he was in the design and application of the machine.

The Paper is illustrated by Plates 1 and 2, and 1 Fig. in the letterpress.

The Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1921.

An ORDINARY GENERAL MEETING was held at The Institution, London, on Friday, 21st January 1921, at Six o'clock p.m. ; Captain H. RIALL SANKEY, C.B., C.B.E., R.E. (ret.), *President*, in the Chair.

The PRESIDENT, having asked the Members to stand, referred to the recent decease of Mr. WALTER PITT, who had been a Member of Council from 1907–1917, when he had resigned owing to ill-health. He had been a Member of the Institution since 1883. Mr. Pitt had taken a great interest in the Wire-Ropes Research Committee, over which he had been Chairman from its inception in January 1914 until his retirement at the end of 1917. The Council that day had approved of a letter of condolence being sent to Mrs. Pitt.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that, in accordance with Article 23, the President, two Vice-Presidents, and seven Members of Council would retire at the ensuing Annual General Meeting; and the complete list of those retiring was as follows :—

PRESIDENT.

Captain H. RIALL SANKEY, C.B., C.B.E.,
R.E. (ret.), ... London.

VICE-PRESIDENTS.

Sir ROBERT A. HADFIELD, Bart., D.Sc., D.Met., F.R.S.,	Sheffield.
The Right Hon. Lord WEIR, P.C., D.Sc.,	Glasgow.

MEMBERS OF COUNCIL.

*Lt.-Col. A. E. DAVIDSON, D.S.O., R.E.,	London.
H. S. HELE-SHAW, LL.D., D.Sc., F.R.S.,	London.
Sir GERARD A. MUNTZ, Bart.,	Birmingham.
Eng. Vice-Admiral Sir HENRY J. ORAM, K.C.B., F.R.S.,	London.
*LOUGHNAN ST. L. PENDRED,	London.
WILLIAM REAVELL,	Ipswich.
*DAVID E. ROBERTS,	Cardiff.

The following were then nominated by the Council for election with their consent :—

FOR PRESIDENT.

Captain H. RIALL SANKEY, C.B., C.B.E., R.E. (ret.),	London.

FOR VICE-PRESIDENTS.

Sir ROBERT A. HADFIELD, Bart., D.Sc., D.Met., F.R.S.,	Sheffield.
H. S. HELE-SHAW, LL.D., D.Sc., F.R.S.,	London.

FOR MEMBERS OF COUNCIL.

Lt.-Col. A. E. DAVIDSON, D.S.O., R.E.,	London.
Sir GERARD A. MUNTZ, Bart.,	Birmingham.
LOUGHNAN ST. L. PENDRED,	London.
WILLIAM REAVELL,	Ipswich.
DAVID E. ROBERTS,	Cardiff.

The following nominations were also made by the Council for election at the Annual General Meeting, with their consent :—

FOR MEMBERS OF COUNCIL.

Election as member.		
1907.	H. I. BRACKENBURY, C.B.E.,	Newcastle-on-Tyne.
1903.	ALAN E. L. CHORLTON, C.B.E.,	London.
1900.	FREDERIC W. C. DEAN, M.B.E.,	Woolwich.
1889.	LUCIEN A. LEGROS, O.B.E.,	London.

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* Appointed during the year.

Election as member.		
1890.	Frederick H. Livens,	Lincoln.
1897.	William Mills,	Birmingham.
1900.	Ernest W. Petter,	London.
1895.	Clarence O. Ridley, O.B.E.,	London.
1919.	Thomas E. Stanton, C.B.E., D.Sc., F.R.S.,	Teddington.

The President reminded the Meeting that, according to By-law 26, any Member, or Associate Member, was then entitled to add to the list of candidates.

No other names being added, the President announced that the foregoing names would accordingly constitute the nomination list for the Election of Officers at the Annual General Meeting.

The President announced that the following 46 Candidates had been duly elected :—

MEMBERS.

Clark, Bernard Francis,	Manchester.
Griffiths, Francis Henry,	Birmingham.
McInnes, Oswald Henry,	Hull.
McMurray, Ralph,	Bombay.
Marshall, Robert,	Manchester.
Maryon, James Frederic,	London.
Ogilvie, Alexander, C.B.E.,	London.
Swan, Percival,	Cairo.
Vickery, Frederick William, O.B.E.,	London.

ASSOCIATE MEMBERS.

Adam, Allan,	Paisley.
Archbutt, Reginald Charles,	Highbridge.
Birks, Norman Arthur,	Sheffield.
Brentnall, John Alfred,	Bedford.
Candy, Herbert Ernest Law,	London.
Cleverly, Arthur William,	Tredegar.
Drummond, Roy Macgregor,	London.
Duncanson, James,	Glasgow.
Grayburn, Robert Clement,	Doncaster.
Hay, Lionel Frank,	Chesterfield.
Keevill, Robert Graham,	London.
Lowdell, Sidney John, Major, R.A.O.C.,	Dusseldorf.
McNaughton, Alexander,	Brighouse.
Montgomrey, James Edward,	London.
Nicholls, Edmund George,	Stafford.
Oxbrow, John Frederick,	Manchester.
Pile, John Edward,	London.
Poole, John Wright,	Bradford.

POOLEY, Francis Henry, Capt.,	London.
REVILL, John Joseph Carus, Capt., R.E.,	Audruicq.
RONS, Richard Frederick,	Dartford.
SINGLETON, Alfred Bruce,	Matania, Egypt.
SMITH, Frederick Leedham,	Scunthorpe.
STILES, Herbert,	Farnborough.
SWAN, Andrew,	London.
VENNING, Septimus Edward,	London.
WARD, William,	Dudley.

GRADUATES.

ARNOLD, Norman Henry,	London.
BATTEN, James Denne,	London.
COOKE, Armor,	Southampton.
GAULD, Richard Douglas,	London.
KINGSTON-MCCLOUGHRY, Edgar James, Capt., D.S.O., D.F.C.,	London.
LEWIS, Eric Hadfield,	Manchester.
OWEN, Watkin,	Liverpool.
PINCHBECK, Arthur Samuel,	London.
WALL, Lewis Alan,	Loughborough.
WHITEHOUSE, Harry Edward,	London.

The PRESIDENT announced that the following three Transferences had been made :—

Associate Members to Members.

ALLCOCK, Harry,	Manchester.
MACKIE, Tom Darke, Col., C.M.G., O.B.E.,	London.
REID, Robert Whyte, C.B.E.,	Derby.

Mr. F. T. PARKER presented the following Paper :—

"The Mechanical Loading of Ships," by H. J. Smith, of Shanghai, *Member*.

The Meeting terminated at a Quarter to Eight o'clock. The attendance was 138 Members and 56 Visitors.

The Paper by Mr. SMITH was also presented by Mr. Parker at :—

MANCHESTER, in the Engineers' Club, on Thursday, 27th January ; Mr. WILLIAM FOX, *Member*, in the Chair.

THE MECHANICAL LOADING OF SHIPS.

BY H. J. SMITH, OF SHANGHAI, *Member*.

Introductory Remarks.—The number of new plants installed for the mechanical loading and unloading of material in bulk, namely, aerial ropeways, belt- and bucket-conveyors, wagon dumpers, and grab transporters, have increased rapidly during the past decade. Designed at first to release manual labour for operations requiring more skill, the methods employed have so improved in utility that there are now few instances where the machinery mentioned cannot do this class of work with greater expedition and economy than the cheapest of coolie labour.

Some of the new plants, especially those designed for the loading and unloading of ships, have so grown in size and capacity that they are now included amongst the larger engineering problems of the day (*see* Figs. 1–3, Plate 3).

Great Britain must always remain interested in the cheap and rapid transport of coal, coke, limestone, iron, manganese, and other ores, because, without the means to do this work at a low cost, she cannot regain and maintain the supremacy in the production of iron and steel that was once enjoyed.

Primary Transporters.—It may be interesting to recall that the principal cause contributing to that supremacy was the fact of this country being first in the field with the cheapest and most rapid means of transporting minerals in bulk, for it should not be forgotten that both the railroad locomotive and the steamship owe their inception principally to the necessity of devising a more efficient means of moving the growing output of the English coal mines.

These primary transporters gave Britain a good start, but other nations came quickly into line and then extended the use of machinery until this country was passed, before the war, in the production of iron and steel by the United States and Germany.

The Author thinks it will not be denied that one of the principal reasons for the success of the nations named, was the attention they paid to the handling of materials in bulk by machinery designed to accelerate the feeding of their steamships and railways.

Competition.—The continual rise in the cost of labour will make mechanical connecting links between the prime transporters and the factories a matter of vital importance in the future, if we are to feed our furnaces from abroad and still hold our position in the markets of the world against the competition that will have to be faced. Competition will be fierce, especially so from the Far East, where Japan and China will be competitors in the future, instead of customers as in the past.

In China, to-day, vast deposits of iron, manganese, limestone, and coal, are being worked and manufactured into iron and steel of all sections by Japanese enterprise, and by the most modern machinery that can be purchased in Europe and America. The new blast-furnace plant now being erected on the banks of the Yangtzse Kiang, at Tayeh, is designed in multiples of 450-ton units for an output capacity of 3,600 tons of pig-iron per day. The loading and unloading appliances, although built in Britain, would be difficult to match by any similar undertaking in this country. Other instances could be given of works in China financed and controlled by the Japanese, but one in Manchuria will suffice, namely, the Anshanchan Iron Works, which are now being extended for an output of 1,000,000 tons of pig-iron per annum.

Machinery v. *The Coolie.*—One point that cannot be ignored is the fact that these Chinese and Japanese ironmasters are installing belt-conveyors and bridge transporters to replace a class of manual labour that has always been considered the cheapest in the world. In short, these competitors are beginning to look upon the cost of transport as a loss which must be eliminated, as far as possible. Speaking generally, ore must be moved to the coalfields, or coal be taken to the ore, and the methods employed are worth all the attention that engineers can give them.

Skilled labour expended on materials during manufacture increases their value, but money spent on moving minerals from the mine to the furnace increases their *cost* but does not increase their *value.* Competition will see to that. This cost of transport will become, eventually, the deciding factor in future manufacturing success. In fact, the lowering of the cost of production by suitable mechanical means is the elemental problem underlying the whole subject of successful competition in the markets of the world; and the solution of that problem is essentially a task for the engineer.

Some Successful Methods.—In the present Paper the Author proposes to deal with four plants which have proved that coal and ore can be transported, loaded into steamers and unloaded, at less cost than was possible previously by using native manual labour. The plants described are not claimed to be the last thing in handling materials in bulk mechanically, or to be more successful than several others which could be cited; they are chosen from a number of which the Author has had experience because they have been installed recently, and illustrate the four most popular methods at present in use. By adopting these means, mines which had been considered hopeless propositions on account of their distance from some existing means of transport, are now being worked at a profit, because docks, in some cases, can be dispensed with, and the steamers loaded whilst lying at anchor in the open sea at some point along the coast where there is sufficient depth of water.

Rocky shores and precipitous cliffs, previously avoided by shipping, are now sometimes sought for because they mean deep water close inshore, and the height of the land above the water level can be utilized by building the loading plant down an inclined plane, thus enabling the machinery to be driven by the gravity of the load and so save the cost of motive power,* Fig. 4, Plate 4.

Formula.—The formula given in the Appendix (page 102) is quite empirical, and has been obtained by the Author from experiments on many plants during the past fourteen years in different parts of the world. The figures have been checked by actual practice under working conditions, especially the portion dealing with belt-conveyors, so that the results are given with some confidence of their being followed with safety by those interested in this class of machinery. The lack of similar details in many engineering handbooks has caused the Author to pay more attention to this part of his subject than would otherwise have been necessary.

AERIAL ROPEWAYS.

The exploitation of a mineralized deposit calls, in the first instance, for some successful method of connecting the mine with any existing means of transport—usually the sea, a river, or a railway. Failing this, the mineral must remain unwrought, as is the case to-day with that stupendous body of iron and manganese ore overlooking Morro Velho, in the State of Minas Geraes, Brazil; although even this inland deposit—perhaps the finest remaining unworked in the world to-day—is beginning to receive the attention of British and American ironmasters.

Sebabna Mines.—A more favourable instance is the Sebabna mine, situated just on the Algerian side of the Moroccan frontier, about seven kilometres from the Mediterranean. This iron and manganese proposition was discovered under an overburden of limestone by an Englishman. The mineral outcropped about 700 feet above sea level, but so rugged is the intervening country that the sea cannot be seen from the mine. Building a railway to the coast over such a contour was out of the question, and transport to the nearest port (Oran) would have cost much more than the mineral was worth. The only alternative was to carry the ore over the hills by an aerial ropeway and ship it by mechanical means into steamers lying at anchor in a small indent in the coast line—partly sheltered by Kap Kelah—where there is a good anchorage, and a minimum depth of 24 feet of water within 250 feet of the shore, Fig. 6, Plate 4.

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* See *Engineering*, 28 Dec. 1917, pages 682–4.

The safety of the vessels demanded a loading appliance of so large a capacity that it would be possible for the boats to anchor under the plant at daylight and clear before dark with a full cargo. In spite of a mistake being made in deciding on a chain of buckets —instead of a rubber and canvas belt—for the conveying portion of the loader, the plant went to work and handled the ore from the mine adit to the ship's hold for a working cost of less than sixpence per ton. To this must be added interest and depreciation charges on the capital expended on the installation. This cost varies, of course, with the output of the mine, but may be considered in the present instance at fivepence per ton.

The situation of the terminal stations for the aerial ropeway was decided by the positions chosen for the loading plant on the coast, and at Sebabna by regard to the future development of the mine. The lode was first uncovered and attacked from the side of the hill by open cast, and then proved to a further depth of 200 feet by sinking and driving. The result being satisfactory, an adit was driven at the lower level from near a site suitable for the ropeway station and connected to the open cast level by a vertical winze which allowed the mineral to be lowered to adit level by gravity, the full wagon coming down serving to pull the empties up without the need of motive power.

Sebabna Ropeway.—The side-tip wagons on leaving the adit travel a short distance along a level track to the ore pocket, or storage bunker, which is simply an excavation in the rocky ground surrounded and divided by massive stone walls, built of rock spoil, to increase the holding capacity to four thousand tons. These walls also carry cross girders which support several tracks and turntables to enable the ore to be dumped into every part of the excavation.

Still taking advantage of the slope of the hill a tunnel under the excavation was driven in a loop (like a horse-shoe in plan), so that the empty ropeway buckets could travel round the circuit and be loaded by one of a series of valve-controlled chutes which connected the tunnel to the storage. The spoil from the tunnel was tipped near the outlet to improve the site for the ropeway terminus and engine house. A 15 N.H.P. single cylinder horizontal steam-engine and boiler were erected in the latter and connected to the haulage-drum through a friction clutch for starting up the ropeway; but as the station at Sebabna is 462 feet higher than the discharging station which feeds the storage bunkers for the shipping plant at Kelah, nearly seven kilometres away, the engine-clutch is thrown out of gear as soon as there are sufficient loaded buckets on the line to work the ropeway by gravity. The driver then shuts down the engine and controls a powerful brake for regulating the speed of the buckets. Any tendency to jerk the ropes by an imprudent use of the brake is prevented by a special fly-wheel fitted with adjustable vanes which act as an air brake, or blower. This fly-wheel requires so much power to revolve it beyond a certain velocity that any dangerous runaway of the line of buckets is extremely unlikely.

The buckets are of gravity tipping type, designed to carry half a ton of ore, and are suspended from a two-wheeled carriage running on ball-bearings, Fig. 5, Plate 4. They are fitted with a clamping arrangement which enables the whole weight of the bucket and load to be utilized for gripping the haulage rope. The loaded buckets, after leaving the tunnel, run down an inclined mono-rail to gain sufficient momentum to pass through the automatic locking device which clasps them on to the haulage rope whilst they are travelling at approximately the same speed, namely, two metres per second.

The buckets are loaded and released from the tunnel at intervals of 45 seconds making a total of 40 tons of ore transported per hour.

The $1\frac{1}{4}$ inches circumference haulage rope is of the usual six strand construction with hemp core, the total length of nearly fourteen kilometres being joined up to length on the site by running splices about 30 feet long. The two bearer ropes are of lock coil pattern, the rope carrying the loaded buckets being $1\frac{3}{8}$ inches diameter and the return rope $\frac{15}{16}$ of an inch diameter. They were joined on the site by the taper socket, screwed coupling and sleeve arrangement in general use for this class of work. Both bearer ropes are supported on steel trestles by passing over cast-iron shoes mounted on rocker arms which allow the bearings to adjust themselves to the varying sag of the ropes. These shoes are fixed 6 feet 6 inches apart, the loaded rope being 2 feet 11 inches and the return rope 3 feet 7 inches from the centre of the trestle, the difference in leverage being balanced by the difference in load.

The trestles are built of steel angles bolted up in the form of taper towers to the height demanded by the various sites, the shortest being 14 feet and the tallest 75 feet high. The standard worked to, fixed the distance between the centres of the holding down bolts at one fifth the total height of the trestle.

Terminal and Tension Stations.—The two terminal stations and the three intermediate tension stations are fixed as near equidistant as possible when using intervening hill tops for the purpose. These stations are built of steel channels braced with angle and bolted to substantial concrete foundations which take the pull of the outgoing rope without stressing the structure. The terminal station at the mine, Fig. 7, Plate 4, serves as the first anchorage, the three intermediate stations are combined for both anchorage and tension, Fig. 8, Plate 5, while the structure at the shipping end carries the final tension weights.

The trestles and stations are all fitted with rope sheaves $16\frac{1}{2}$ inches diameter, working on $1\frac{1}{2}$ inch pins (arranged for automatic lubrication) to take the weight of the haulage rope when it sags between buckets. These sheaves are supplied with long splayed guide-bars to ensure the rope finding the tread of the pulley in spite of any swaying caused by high winds, Fig. 9, Plate 5.

The bearer ropes are kept under proper tension by boxes made of $\frac{1}{4}$-inch steel plate filled with shingle, those for the loaded ropes being 6 feet square by 9 feet deep, and for the return ropes $4\frac{1}{2}$ feet square by 9 feet deep. The larger ones weigh, when filled, about 12 tons and the smaller 8 tons.

In practice, these weights are continually rising and falling as they adjust themselves to the varying load on the ropes, the extreme travel between cool morning and hot afternoon being something considerable. They are suspended in a concrete-walled well, which forms part of the foundation and are kept from contact by guides which serve also as columns to support the bend sheaves which are three feet in diameter and brass-bushed to turn on 6-inch gudgeon pins. The treads are machined to take four parts of flexible steel rope socketed to the lock coil bearer ropes by a special cross-head.

Storage Bunkers.—The terminal station at the shipping plant end is fixed over the storage bunkers which are constructed in a manner similar to the one already described for the opposite end, except that this one has a capacity of 12,000 tons and is divided into three compartments by two massive walls built from spoil rock, which supports the ropeway station at a sufficient height to clear the apex of mineral which forms as the bunkers are filled, Fig. 11, Plate 5.

Like many other jobs, these bunkers could be improved if they had to be repeated. The sloping sides of the excavation were not made steep enough. It is best to forget all about the angle of repose when building bunkers for the storage of minerals, especially if they contain much dust and are exposed to the weather. The way that iron ore will stand on a slope of 50° from the horizontal must be seen to be realized. The ore pocket under review had six chutes leading to the conveyor in the tunnel underneath, and it was not uncommon to see a vertical shaft opened up over each chute about 40 feet deep and with sides standing solid only 15° from the vertical. Men had to be put in with long steel bars to break the walls and start the ore running, and the job was at times so dangerous that the Author found it advisable to do the work with a stick of dynamite and fuse poked into a likely crevice by means of a long bamboo. Recent American practice in the construction of steel bunkers for iron ore is in the right direction, and excavations forming ore pockets should follow the same lines and have the sides cemented as smooth as possible.

The Sebabna Ropeway went to work without any hitch (except those here recorded), and when the Author left, it was handling 12,000 tons per month on a ten-hours' day shift. The cost, ready for work, was a little less than £15,000 (fifteen thousand pounds), but it should be remembered that the work was concluded in 1913.

Formula for ascertaining the power required to drive aerial ropeways will be found in the Appendix (page 106).

BUCKET-CONVEYOR SHIPPING PLANT.

The Conveyor.—This ship-loading plant receives iron ore from the 12,000-ton storage under the ropeway just described. It is probably the biggest bucket-conveyor yet built, and consists of an endless chain of steel buckets 564 feet in length between the centres of the pentagon tumbler at the head and the tension wheels at the tail end, Fig. 10, Plate 5. Each bucket can carry half a ton of ore: 274 feet of the chain is carried out over the water on a cantilever structure weighing 300 tons and supported at the centre by a trestle mounted on two cylinders sunk in the open sea, Fig. 6, Plate 4. The remainder of the chain is in the tunnel under the storage, except for a short length which is carried by a separate structure connecting the bridge with the tunnel, Fig. 12, Plate 6, and spanning a block of 500 tons of concrete, reinforced and set into the shore rocks to serve as abutments and loading for the anchor arms against the pull of the cantilever.

The maximum upward pull of 100 tons on the holding-down bolts securing the anchor arms to the foundation is not due to any greater length of the cantilever, but is caused by the weight of a separate chain of buckets working on a light steel structure, forming a carriage, the trod wheels of which move on rails suspended below the bottom boom of the cantilever. This carriage and its chain of buckets can be run under the bridge until it is flush with the nose of the cantilever, or it can be moved out 42 feet beyond the nose by winches provided for the purpose. This arrangement allows steamers to come alongside, and then be warped fore and aft, to bring the several hatches under the plant without risk of fouling the structure. Further, any tendency of the steamer to list whilst loading can be checked by telescoping the carriage as required, and this can be done without stopping the plant or interfering with the loading operations in any way.

The main chain of buckets receive their load from one or more of six valve-controlled chutes fitted to the roof of the tunnel under the storage. The buckets are made continuous by overlapping, so that a constant stream of ore can fall from the chutes without risk of spillage. Regulation is made by hand-controlled mechanism for flattening or increasing the angle of a steel apron which extends from the chute to within 6 inches of the buckets.

The tunnel is driven into the rocks, which rise almost sheer from the sea at this point, and the structure forming the runway for the buckets is carried by steel columns cemented in the roof and floor of the tunnel, which at first terminated in a dead end 300 feet from the face. But when loading commenced, the dust from the ore in dry weather became so dense that it obscured the artificial light, and the Arabs refused to remain at their post, so the Author continued the tunnel on a rise of 45° until it emerged beyond the storage. The floor was blasted out in rough steps so that it served as a separate exit as well as a ventilator.

The bucket track in the tunnel is horizontal, but turns up with an easy radius to an inclination of 4° before reaching the bridge, which is set at that angle. The concrete abutment which carries the anchor arms is 23 feet above high water, or 8 feet lower than the trestle and cylinders supporting the centre, so that the nose of the cantilever is 39 feet above high-water level.

It may be noted here that, if the cliffs had been a little more favourable in contour, it would have been possible to build the bridge *down* instead of *up* an incline, in which case the conveyor would have worked automatically by gravity of the loaded buckets instead of requiring motive power, as in the present case.

The Structure.—The total length of the bridge is 284 feet when the movable portion is housed underneath, and 326 feet when fully extended. The bridge girders are 30 feet deep at the centre and 15 feet apart. They are secured by bracing fixed to both top and bottom booms. The anchor arms and cantilever arms are identical in length and construction, each having eight panels of 17 feet 9 inches centres.

The cylinders which support the weight at the centre are 8 feet in diameter and pitched 30 feet centres apart. They were sunk through the sand under 17 feet of water, and continued 2 feet 6 inches into the solid rock by blasting in the usual manner, the air-lock being placed in position after as much sand as possible had been dredged out. Diving apparatus was used when fixing bottom weight to the cylinders, and, incidentally, to recover the large number of tools dropped overboard when building the bridge by Arab labour. The cylinders were pitched by means of a floating crane improvised on the site from two 30-feet lighters lashed beam to beam (but 8 feet apart) by four timbers 9 inches square by 40 feet in length. To these timbers were spiked 9-inch by 3-inch deals to form flooring and stiffen the construction on which was mounted the winch and counter-weight. The jib was erected to overhang the side of one lighter sufficiently to give clearance for the cylinder when hanging in the tackle for lifting and pitching.

The cylinders were afterwards filled with concrete to a height of 7 feet 6 inches above high water where they terminated as a base for the steel trestle 23 feet 6 inches in height, making a total of 31 feet above high water or 33 feet above low water, the rise and fall of the Mediterranean at this point being only 2 feet.

All the gear, stores, and material for the job were shipped to the site by a small steamer specially chartered for the purpose, and which lay at anchor while the cargo was landed by the two lighters previous to their conversion into a floating crane. A 5-ton hand crane with a 50-foot jib was first unloaded and set up on some rocks just above high water level for lifting the goods from the lighters and slewing them round to a patch of beach behind. A workshop and store were built on the same site, and an inclined track laid up to the mouth of the tunnel to carry the conveyor parts and engines, and also to transport aggregate from the beach for mixing the concrete required for the abutment. Most of the bridge work and all parts appertaining thereto was floated out to the site by the lighters, and there delivered to a 5-ton Scotch derrick mounted on the bridge falsework.

Power and Drive.—The two I.C. engines each of 50 b.h.p. semi-Diesel type required for the conveyor were first used for driving the air-compressor and other erection work, before being placed on their foundations in a house built on the bridge abutment where they were arranged to drive the same countershaft, through friction-clutches, to act as auxiliaries or together as desired. In practice it was found that both were required, because the Arabs controlling the chutes in the tunnel often filled a long line of buckets to overflowing, which put so much load on a single engine that it slowed down until the vaporizer cooled enough to stop work.

The countershaft is fitted at the centre with a 7-feet diameter rope-sheave and placed in line with a similar sheave on the cantilever end of the bridge, the distance between the two centres being 285 feet. The driving medium is an endless steel-wire haulage rope, 2¼ inches in circumference, joined to the length required by a 40 feet running splice, the speed being 4,400 feet per minute. The rope-sheave on the bridge is carried by an outboard bearing so that the slack wire driving rope running parallel to the bridge has sufficient clearance to prevent the risk of striking the structure when swaying.

The power is transmitted from the sheave to the driving tumbler through gearing and a "Hele-Shaw" clutch. The gearing also meshes with a further train which drives the telescopic conveyor at a 25 per cent increase in speed to avoid any risk of spilling ore into the sea, when the main chain of buckets happen to be overloaded. A novel feature in this drive is the equalizing gear invented by I. C. Barling, Esq., M.Inst.C.E., to overcome the surge caused by the variation in speed of a heavy chain of buckets.

Previous plants had proved that in the case of a five-sided tumbler, the velocity of a chain of buckets when the tumbler was rotating at a uniform speed, varied as much as 25 per cent during the cycle of passing a single cant of the tumbler. This drawback limits the speed of a large articulated belt to less than 100 feet per minute. Even at this speed the effect of 50 tons of loaded buckets surging along the bridge was feared; it was avoided, however, by the intervention of an epicyclic train, operated by a cam, which varied the angular velocity of the driving tumbler and gave a uniform speed to the buckets, Fig. 13.

FIG. 13—*Equalizing Gear* (Barling).

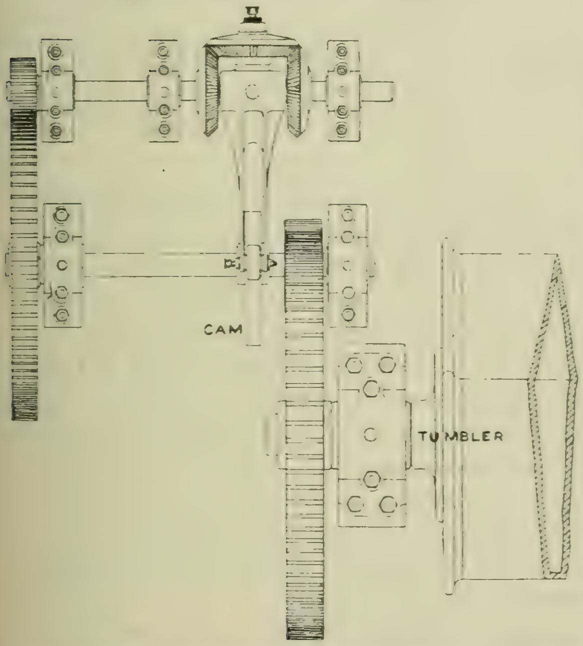
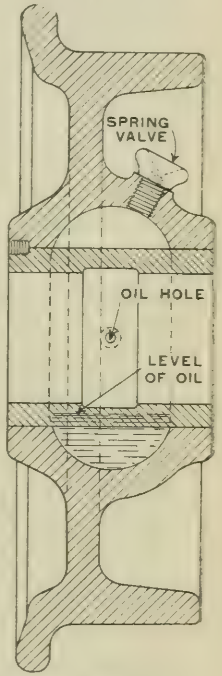


FIG. 14—*Automatic Lubricating Bucket Wheel.* Scale ⅓ full size.



The trod wheels on the bucket chain were fitted with Stauffer lubricators; but the Arabs proved poor greasers and the cups were frequently lost overboard, or else filled as much with ore dust or grease, with the result that wear on the 750 wheels and axles became abnormal. The Author had some spare wheels counterbored and brass-bushed, so that the annular space on the outside of the bushes served as a reservoir for automatic lubrication, Fig. 14. Oil was fed to the reservoir by being forced through a spring valve (similar to those used for bicycle hubs) by a syringe which contained the proper quantity for one wheel. The syringe has a taper nose ground to fit the valve, and is held hard up whilst filling. The arrangements were made as "fool proof" as possible, and the results were satisfactory.

Loading Steamers.—The steamers were moored in position under the plant by three floating steel buoys attached to 2-ton stockless anchors and two bollards bolted to the rocks on the fore-shore. Two of the floating buoys were placed directly fore and aft of the ship's loading position for warping ahead or astern to bring the various hatches under the loader. The buoy to seaward and the two bollards ashore, together with the ship's own anchor made all safe abeam. It was found in practice that, by dumping the ore as near to the fore and aft extremities of the hatchways as possible, and working the telescopic conveyor to avoid any tendency to list, the full load could be dumped into the holds before the cone of mineral rose high enough to choke the hatchway. This reduced trimming to a minimum, as it only required a few Arabs to shovel the apex of mineral down the sides of the cone to complete the job.

The greatest speed of loading attained by the Author was 660 tons in fifty-five minutes, namely, filling one hold of the S.S. "Poeldijk"; but the friction, due to the poor lubrication previously alluded to, caused the engines to run below full speed. There is little doubt that when the wheels of new design are completed—the first lot was captured by the enemy—and the Arabs become used to their work, the plant will easily attain its rated capacity of 800 tons per hour.

When the conveyor was at work under full load, the vertical oscillations of the cantilever were rather alarming to the operators. The greatest amplitude of these vibrations, as shown on a scale painted on the nose of the cantilever, and taken from 100 readings recorded by the Author with a transit set up on shore, was $2\frac{1}{2}$ inches, whilst the period was seventy to the minute. This period in no way synchronized with any of the mechanical movements on the bridge and there was no suspicion of resonance, but it was considered advisable for the Author to make a second visit to Algeria and strengthen the structure on that part of the bridge which carried the drive. But the results were not different; the vibrations worked up to a maximum of $2\frac{1}{2}$ inches and then gradually damped down again.

The Author thinks that a mistake was made in fitting an articulated chain of buckets to the plant: it seemed an ideal case for a belt-conveyor. A fabric and rubber belt 48 inches wide, travelling at 400 feet per minute, would have carried a bigger load for less power, while the weight on the structure, and the vibration, would have been considerably different. The owners, however, had no faith in this arrangement, and insisted on a chain of steel buckets. The cost of the Cableway and Shipping plant (pre-war prices) erected complete was about £35,000 sterling.

BELT-CONVEYORS.

To an engineer of the Mersey Dock and Harbour Board belongs the credit of inventing the Belt-Conveyor. His first idea of moving grain by means of a worm screw was abandoned because the capacity was too low and the power consumed too high. After numerous experiments with various mechanical devices, Mr. G. H. Lyster decided that a rubber and canvas belt was best adapted to his purpose.

During the same year he perfected the "tripper" or throw-off carriage, which is still used for discharging the load at right angles to the belt.

For moving minerals along the level or on an inclination not exceeding 20° above or below the horizontal, the belt-conveyor transcends all its rivals both for simplicity of construction and economy of first cost, while its proved capacity for handling iron-ore at the rate of 2,000 tons per hour by no means exhausts its possibilities.

After the outbreak of War it was believed, not without reason, that the Turks would make a determined effort to capture or block the Suez Canal, which manœuvre, if successful, would have thrown all the work of coaling steamers for the Far East on the South African ports. In preparation for this possibility, the South African Administration for Docks and Railways gave orders for the construction of a large Belt-Conveyor Shipping Plant at Durban, with a guaranteed capacity for loading coal into steamers at not less than 30,000 cubic feet per hour. The fact that the South African Government chose a belt-conveyor when they required a plant to ship coal at the rate of 700 tons per hour during a time of great national danger is of more than passing interest, although in their case it was probably a natural sequence, because in gold mining the problem of transporting many thousands of tons of rock daily through the various processes in the reduction department had resulted in the triumph of the belt-conveyor over all other methods.

Belts: Life and Capacity.—In the first place the durability of the moving parts of a belt-conveyor is greater than generally supposed, although a few moments' reflection on the amount of work an auto-car tyre will stand up to should convince anyone what the life of similar material ought to be when working under more favourable conditions on a conveyor.

A belt 30 inches wide made up of 8 plies of cotton duck faced and filled with rubber is known to have elevated two million tons of coal while working at a speed of 460 feet per minute at a South African Colliery. The best performance of this inclined conveyor was 3,000 tons in 10 hours, and it should be noted that no guide-idlers were used. The Author changed a belt after it had been in commission for five years loading iron ore into steamers on the Spanish-Mediterranean coast. The speed of this belt was 300 feet per minute. A similar belt 42 inches wide with $\frac{3}{16}$ inch of rubber on the working face shipped 3 million tons of ore at another Spanish port and made the record of 1,500 tons carried in one hour.

Makers should be willing to guarantee the life of a 48-inch belt at not less than one million tons of coal carried, if allowed to supervise the erecting of the plant.

There are several types of belting suitable for conveyors, and for all of them there is claimed some superiority. But the choice of a belt for this class of work depends on several considerations. If the conveyor has to work in the open air, or carry wet material or stuff containing destructive acids, then the Author considers it a waste of time to argue against a rubber-covered belt. If an engineer is in doubt which is the best class of belt material for his particular purpose the matter is easily settled, because belting will work quite well on a conveyor if joined up in two or more pieces by "Bristol" lacing. This test is conclusive, as the sections can be watched while working under exactly the same conditions.

Generally speaking, a low-priced belt is false economy, and it is worth noting that the most expensive brands retain their market.

Conveyor-belt failures come usually under three headings:—

(1) Wearing so thin that it is unsafe to run them any longer.
(2) General break-up, through lack of adhesion to bind the layers of canvas together.
(3) Bad treatment of the belt, generally at the edges, through excessive use of guide-idlers (to overcome bad alignment of the working parts) causing stripping of the rubber cover which allows moisture to enter and attack the fabric.

The failures suggest the remedy required.

When examining a sample of rubber belting, the cotton duck should be exposed so that the number of yarns can be counted in the warp and filler, to make sure that the belt is almost as strong across its width as along its length. A good rubber and canvas belt made with cotton duck weighing not less than 30 oz. per square yard should be equal to a breaking strain of 400 lb. per inch per ply. This means that the ultimate tensile strength of a six-ply belt, 24 inches wide, will be about 25 tons. Such a belt would work well on a conveyor when stressed to 2 tons by the tension load and drive. A rubber and fabric belt 30 inches wide by 2,000 feet in length, working on a conveyor nearly 1,000 feet long, at a speed of 350 feet per minute, and loading coal at the rate of 200 tons per hour, will stand a drive of 60 b.h.p. when using tandem pulleys, without unduly stressing the belt. The Author has installed belts 48 inches wide, weighing 12½ lb. per foot-run to load 800 tons of coal per hour when running at 500 feet per minute. A belt 60 inches wide, capable of carrying 3,000 tons of iron-ore per hour, is quite a practical proposition.

The quality of rubber used on the working face of a belt should be capable of stretching three times its length, 3 to 9 inches, before breaking, and the belt will give the best results if in a flexible condition with the rubber rendered not too hard by over-vulcanization. The adhesion of the rubber face to the canvas should require a force of not less than 20 lb. applied for one minute to separate one square inch. The "frictioning" between the layers of canvas should require a force of not less than 16 lb. for the same purpose. A really first-class belt would better these conditions easily.

The best results cannot be expected from any make of belt, unless the structure and mechanical portions of the belt are designed to comply with certain conditions favourable to the belt. There is little information of any practical value on the subject of belt-conveyors to be found in engineering handbooks, and one of the objects of this Paper is to enable engineers to specify the principal portions of the conveyor in some detail when ordering machines of this class.

Competition will cause makers to cut things too fine, for which engineers are partly to blame, because as customers they will be inclined to purchase in the cheapest market. A belt-conveyor with a stated capacity of 500 tons per hour, should be capable of handling 5,000 tons in ten hours, instead of 100 tons in twelve minutes of exceptional circumstances, which is a distinction with considerable difference.

The best speed for belt-conveyors is still open to argument. The Author, considering all things, favours from 300 feet per minute for smaller sizes, up to 500 feet for the larger. The speed should not be less than 300 feet, because the trajectory of the load after leaving the belt at lesser speeds, falls too rapidly towards the vertical to ensure the whole of the stream being discharged clear of the head pulley. On the other hand, with speeds exceeding 500 feet per minute, it is difficult to deliver the load to the belt without serious abrasion. The ideal way of loading would be to let the material come to rest on the belt whilst it was travelling along the same plane, and at the same speed at which the belt was running. This would reduce abrasion to the minimum, and although such conditions are almost unattainable in actual practice, yet the possibility should not be lost sight of when designing feed-hoppers for belt-conveyors.

Feed-Hoppers.—The mistake should not be made of building a hopper to discharge down an angle of, say, 40° from the vertical, to deliver mineral on a belt running up an incline of 20° from the horizontal. Instances of the kind can be found with the result that the "boiling" which takes place before the load comes to rest, has a serious effect on the life of the belt, and is the cause of a deal of spillage. A bad belt-conveyor means either faulty design, poor erection, or a bad feed-hopper. The angle of an inclined belt should flatten gradually into the horizontal from 5 to 15 feet (according to width) before reaching the feed from the hopper.

Regarding hoppers, the funnel may be considered a hopper of sorts, but it will not serve a belt-conveyor. Sharp sand flowing through a sluice gate is the idea to follow. The discharge end of a hopper should have a vertical face. The sides may slope, but they should terminate in a channel with vertical sides of the same depth as the discharge opening in the front plate and then taper to zero, where it joins up, or forms part, with the rear slope. The bottom of the channel should lie at an angle sufficiently steep to deliver the material through the opening with momentum enough to carry it over a spooned plate which will change the direction of the stream into something approaching the horizontal. Dogmatism fails here.

of course, as elsewhere, because with wet sand or sticky material, nothing less than a vertical drop is permissible.

The hopper which will not choke at times has not yet been built. When dealing with sand, crushed rock, or small coal, it is easy to get an even feed from the hopper to the conveyor; but iron-ore or rock varying in size from dust to 18-inch cubes is a more difficult matter, unless there is sufficient fine stuff to float the large lumps singly through the outlet. A wagon-load of lump rock will sometimes form an arch and choke the hopper until the keystone is dislodged by poking. To prepare for this, several poker holes about 2½ inches in diameter should be cut out in the region where wedging takes place, and be covered by a circular plate secured with a single bolt, so that it can be pushed aside when necessary to allow the insertion of a steel bar for levering up the wedged stone until the arch collapses. A lot of time is wasted on most hoppers by trying to clear obstructions through the opening instead of attacking the trouble at its source by this simple arrangement.

Some patience is necessary with new hoppers. Speaking from experience, the Author has wasted time and money making alterations to new hoppers which later on had to be restored to their original form. The difference in the action of mineral running through a hopper worn smooth and bright compared with the performance when the plates were new and covered with mill scale and paint must be watched before it can be fully realized.

During erection it is usual to see the machine-parts guarded against the weather, while the hopper-plates are tumbled into any odd corner to corrode at will. A coat of red oxide after riveting up is completed is supposed to be all that is necessary. When the plant goes to work, the hopper end of the conveyor is looked upon as a necessary evil—a dirty place to be avoided because of the dust, but if conveyors had souls the psychology of the hopper would fill volumes.

Hopper-plates should have the working faces polished under a sand-blast at the works and then be protected with white lead and tallow until ready for work. Even with an old hopper the thin film of oxidization that forms overnight is detrimental, until swept away by a few wagon-loads of mineral.

The ideal mineral for running through a hopper is washed nut coal, although any kind of coal runs better than rock. With reasonable size of coal compared to the hopper opening, the dust acts as a lubricant and the mixture tumbles through in a regular stream on to the belt. Large lumps of any material may be loaded without much hindrance, if the conveyor has sufficient width to pass two pieces abreast and allow the necessary gate regulation to relieve any choking; but it is not possible to get the same duty from the machine as when fed by a constant stream of smaller material, and some poking will be necessary at times to clear the hopper. It is not uncommon to see a conveyor, which could load easily 500 tons of household coal, installed and trying without success to do the same duty on large run of bunker coal. To expect the same result in both cases is unreasonable.

Power Required.—The Author has devised formulæ from practical experience, which will give the average duty that may be expected under different working conditions as well as the maximum which may be expected when all is favourable. It will be noted that the constants given do not vary proportionately with the specific gravity of the mineral to be conveyed, the Author having made an effort by the use of the former to give a more exact indication of the tonnage likely to be conveyed under various conditions than would otherwise be possible.

On the other hand, the constant used when calculating horsepower remains always the same as for maximum loading capacity, because it is certain that any plant will be loaded to spilling point at times and the motor must be capable of carrying the greatest load when called upon.

Furthermore, the incidental flooding of a belt is often the time chosen by the operator for shutting down the plant, so there must be a sufficient margin of power in reserve—especially on an inclined conveyor—to enable this over-load to be started up again from rest without trouble. For somewhat similar reasons, all inclined conveyors should be driven through worm-gearing to overcome any tendency of the belt to run back when stopped in an overloaded condition. The Author was called to inspect two belt-conveyor shipping plants which were earning an unenviable reputation during the first year of the War, because overload caused the circuit breakers to trip, or blew out the fuses and stopped the plant which could not then be restarted until a considerable amount of coal had been shovelled off the inclined belts. The number of men which had to be kept on hand, the noise, the mess and confusion can be imagined. Now another 10 h.p. or so on the motors would have increased the original cost very little and certainly would not have increased the running cost, while the customer would have been satisfied instead of being very much the reverse. Here again makers are not altogether to be blamed because clients are more likely to be attracted by a tender for a plant with a 75 b.h.p. motor than a similar one where 100 b.h.p. is called for. As a matter of fact, the running costs will be less with the latter. The large motor will remain cool and be equal to all emergencies, whilst the smaller one would run hot when overloaded and be often shut down from the same cause.

The formula given by the Author has been arranged to meet these contingencies, and although the resultant figures may be at variance with some makers' ideas on the subject, yet the figures given may be taken as a reliable guide, being tbe result of practical experience with the difficulties they are intended to avoid.

It will be understood that although the motor has sufficient margin to cope with the exceptional circumstances that are sure to happen, yet the power consumed will be proportionate to the average of the load conveyed. There is, of course, a limit to the power which may be employed, namely, the maximum pull the belt will allow the driving-pulley to exert without injury to the fabric. Belts built of cotton duck weighing 30 oz. to the square yard may be stressed to 30 lb. per inch ply with safety. This side of the problem is also taken care of by the formula given.

Structure, Pulleys, and Idlers.—Turning now to the structural portion of the conveyor, it may be stated that many belts are damaged through designers not allowing sufficient clearance between the return belt and the foundation, especially in the region of the tail pulley of inclined conveyors. Numerous examples could be given if space allowed.

Another cause of damage is placing the stringers which carry the idlers too close to the edges of the belt: 8 inches of clearance on each side is not too much. Dust, especially if damp, is likely to build up on the tread of the tail pulley and throw the belt badly to one side before the trouble is noticed, with the result that the belt edges rub hard on the structure if sufficient clearance has not been allowed for.

The greatest menace to the life of a conveyor-belt is the guide-idler. If the belt is compelled to run within narrow limits by the liberal use of guide-idlers, damage is certain. Unequal loading, due to the stream of mineral not falling central from the mouth of the hopper, will cause that side of the belt most loaded to sink into the trough of the idler. This variation is of little consequence and should be allowed for by clearance instead of forcing the belt into line by guides. In nearly all cases of belts with record lives, it will be found that they were run without side idlers.

If there is a place for guide-idlers, it is where they are rarely found, namely, along the return. What the returning belt is doing cannot be seen easily, and as it is running on flat idlers and without load, it can be kept in line with but little wear on the edges. It is also logical to suppose that, if the return is running central, there will be little trouble with the troughed portion, providing the belt is kept under proper tension. In most cases attention to the alignment of pulleys, or the feed from the hopper, will produce better results than fitting guide-idlers. Other causes of "snaky" running may be insufficient tension or the placing of the drive too near to the tail pulley.

When trippers are necessary, it is not conducive of the best results to put the belt under the best tension for straight running. The cure in such cases is to tilt the troughing idlers towards the direction in which the belt is running, by placing wooden wedges with $\frac{1}{2}$ inch of taper under the idler brackets. This tilting has the effect of making the centres through the pulleys follow converging lines, and this overcomes the tendency to snaky running by causing the slack to be taken up in sag between the troughing idlers.

Bend pulleys on a belt-conveyor cause a deal of spillage in their vicinity. The most efficient remedy, and the least harmful, is to replace the pulley by a nest of troughing idlers pitched about 12 inches apart and mounted on steel channels bent in the form of a quadrant, whose radius is about 6 feet centred over the knuckle-pin if the conveyor has a movable arm. About five idlers will be sufficient. When the movable portion of the conveyor is luffed up to its highest position, Fig. 18, Plate 7, only one idler on the quadrant will be in operation, but as the conveyor arm is lowered to the horizontal or beyond it, as often happens in a shipping plant, Fig. 15, Plate 6, one idler after the other comes into commission and the angle is turned while the trough is maintained. Even this method has some effect on the life of the belt, but it is not much, and the advantages due to the absence of spillage far outweigh the slight increase in running cost.

Skirt-Boards.—Another point of spillage is where the feed is delivered to the belt. This can be cured by fitting skirt-plates at the same distance apart as the width of the opening in the feed-hopper, to which they should be firmly bolted. The plates are then splayed until they terminate about 2 inches inside the edge of the belt. The under edges of these $\frac{1}{4}$-inch steel plate skirts should be filed half round and commence with the heel only $\frac{1}{4}$ inch from the belt and rising gradually to the point, which may be $1\frac{1}{2}$ inches or more above the belt. If finer adjustment is required, a piece of wood or belting planed to a feather-edge can be bolted to the skirt-plates so that the edge is just clear of the belt. Slotted holes in these boards will allow for adjustment as they wear. The skirt-plates must be firmly fixed at both ends to the permanent structure and braced in the centres also for the larger sizes. Their length will range from 5 to 10 feet according to the size of conveyor and the nature of the load.

Skirt-plates have some effect on the life of a belt, but so also do roads wear out the tyres of auto-cars. The life of conveyor-belts should be guarded by all means, but in the end it becomes a problem in profit and loss and should not be allowed to become an obsession. The system of belt-conveying may be perfected because all its faults can be eradicated. All the mechanical parts will run for years without repair. The belt is an expensive item to renew, but the cost must be compared with the work it will do. Serious damage to belts, like railway collisions, will surely happen, but the extended use of the one is not likely to be more impaired than the other on that account. The system stands on its ability to transport material in bulk with greater rapidity and economy than any other method. Given good erection and attention to the details mentioned, the belt-conveyor for this class of work stands unrivalled.

Durban Conveyor.—The largest belt-conveyor erected by the Author is the coal-shipping plant at Durban,* which was completed in 1917 at a cost of nearly £50,000, excluding the cost of the foundations. It is designed to load anything from a lighter to the largest vessel afloat, and delivers the coal in a continuous stream which can be varied from 200 tons to 800 tons per hour to suit the ship's requirements. The belt used is 48 inches wide, made with eight plies of cotton-duck rubber filled and covered, and a tread of pure rubber $\frac{3}{16}$ inch thick on the working face. The belt weighs 12½ lb. per foot-run, and has a total weight of over 9 tons.

The plant consists of four units:—

(1) A fixed dumper capable of delivering coal to the conveyor in any quantity up to 1000 tons per hour, by hoisting and tipping railway wagons of any size up to a maximum of 80 tons gross weight.

(2) An inclined belt-conveyor about 200 feet in length, which turns by an easy radius from an angle of 9° under the hopper to 20° for the remaining portion. This conveyor is driven through

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* *Engineering*, 17 Aug. 1917, page 166.

worm-gearing on the head pulley by a 65 b.h.p. variable speed motor, and elevates the coal 60 feet before discharging into the automatic weighing-machine.

(3) The "weightometer" is fixed near the extremity of the third unit which is an horizontal belt-conveyor 525 feet in length between centres running parallel to the quay wall on an elevated gantry. This belt also is driven by a 65 b.h.p. motor in a manner similar to the former, except that it is geared to run 25 per cent faster than the second unit to avoid any risk of flooding the belt, even if this has happened to the first conveyor. This third unit is fitted with an automatic tripper which runs on rails fixed the full length of the gantry, and discharges the coal at any point along the runway as required by the travelling tower or fourth unit.

(4) The travelling tower is a substantial structure weighing 150 tons and designed to run along the quay wall at 80 feet per minute by electric motors geared to both the front and rear bogies. The duty of this tower is to carry a telescopic and hinged belt-conveyor capable of discharging coal at any point over a horizontal plane measuring 500 feet in length by 22 feet in width, or to any point in a vertical plane 500 feet in length and reaching from just above rail level to 60 feet above the water line. In other words, to any point that could be required by the largest liner afloat without the necessity of moving the ship.

The conveyor can be telescoped in or out, lowered or elevated, and the tower moved to and fro whilst the plant is loading coal. The seven electric motors on the travelling tower, together with those operating units Nos. 2 and 3, are all controlled by one man in an elevated cabin where he has an uninterrupted view of the loading operations. The machinery is "fool-proof." Either belt-conveyor shutting down from any cause trips the circuit-breakers of all the motors behind it, and they can only be restarted in their proper sequence. Remote control push-buttons arranged to shut down the whole plant on the instant are placed in various positions in case of need. Each motor is provided with hand-guard cut-outs, by which the system can be shut down from any motor without any risk of being started up again through ignorance of the situation by the main operator.

The contract specified for the erection complete and maintenance for six months before acceptance. The latter period ended in 1917 when the plant was taken over by the South African Administration for Railways and Harbours.

The loading record, so far as the Author is aware, remains at over 800 tons for one hour and 7,000 tons for a working day of 10 hours. The total weight of the structure and machinery is nearly 800 tons and the cost about £50,000 excluding the cost of the foundations.. The power used is 500 volts continuous current and the motors used on the plant aggregate 700 b.h.p. The actual current consumed on the average under maximum working conditions is approximately 150 kilowatts.

WAGON-DUMPERS.

Loading coal direct from railway wagons to steamers by staiths worked hydraulically held favour in this country for a long time, and many engineers of the old school still look with a jealous eye on any rival scheme, but it is now generally admitted that electrical appliances are more economical units.

Comparisons.—If it is assumed that 19 cubic feet of water under a pressure of 750 lb. to the square inch is equal to one b.h.p. hour, then it may be concluded for the sake of comparison that, taking a basis of hoisting coal 25 feet before it can be tipped, the hydraulic hoist will dump 4½ tons, the electric hoist 5½ tons, and the belt-conveyor 7½ tons per b.h.p.

It may be stated here that a belt-conveyor could be installed for half the cost of a dumper, and the former unit would have the advantage of being easily constructed to run along the wharf and load into all hatches without the necessity of moving the steamer. This increases the mooring capacity of a wharf nearly 50 per cent, and as each foot of wall represents so much capital invested the consideration is a very important one.

Wagon-dumpers can, of course, be made capable of propelling themselves along the wharf, but the cost is then prohibitive compared with the belt system. This statement implies no inherent objection to wagon-dumpers, for the Author has installed one of the largest machines of the latter type. But the fact that the N.E. Railway Company scrapped a double hydraulic hoist at the Victoria Docks, Hull, and replaced them by two belt-conveyors, leaves no doubt which type of loader they found most economical.

Comparisons between home and foreign coal shipping records are difficult. In this country the small end-tipping type of wagon is used almost exclusively, whilst large side tipping and bottom dumping wagons find more favour abroad. Two electrical staiths in Glasgow are reported to have tipped 70,604 wagons containing 556,419 tons of coal in twelve months. This gives an average of 7·88 tons for British wagons.

Two electric dumpers on the American Atlantic seaboard claimed the worlds record in loading coal by dumping 930 wagons containing 45,500 tons at an average rate of $1\frac{3}{4}$ minutes per wagon. These figures give an average of nearly 49 tons of coal per wagon. The rate of loading implied, namely, 1,677 tons per hour for each machine, cannot be beaten by any dumper existing in this country. Other sensational figures have been published from time to time, but twenty-four years' experience installing big plant has made the Author suspicious of freak conditions assisting these wonderful performances. In an engineering court of inquiry, the number of tons loaded in a year, divided by the number of hours work for which the operators have been paid, would be considered better evidence than stray paragraphs from the technical Press. The best loading figures for the United Kingdom of which the Author is aware is 4,000 tons in $12\frac{1}{2}$ hours by an hydraulic tip at a South Welsh port.

The Author found the larger wagons running on a metre gauge over the South African Railways to have a capacity equal to 35 tons of coal and a gross weight of 80 short tons. Here lies the secret of the different methods of tipping the contents, for while it is easy to tip the small British wagon up endwise without damage, the greater weight of foreign wagons if thrown on one pair of wheels would strain the horns, and axles, and perhaps displace the springs. With the larger type of wagon mounted on two sets of bogies, end-tipping is, of course, out of the question. Our American friends might remember that when laughing at our "match boxes on wheels."

Side-Tipping Dumper.—The electric wagon dumper installed by the Author at Durban, Fig. 16, Plate 6, deals with 75-ton wagons or two smaller wagons aggregating not more than that amount. The dumper is designed for hoisting and dumping 1,000 tons of coal per hour as a maximum. But in actual practice, short bursts at the rate of 1,300 tons per hour have been noted. There would be no difficulty in maintaining an average of 800 tons per hour.

The total labour force employed on the machine is four persons, namely, one operator who controls the master switches in a house placed high enough to give him a complete view of all the operations, one driver watching the hoists and automatic electrical contactors, one greaser in the engine rooms and one man who watches the "mule" or mechanical shunter and applies the brakes if for any reason the "mule" fails to follow and overtake the wagon ascending the incline. Four men to dump 1,000 tons of coal per *hour!* It would require more than that number of timekeepers to check up sufficient men to move that amount in a *day* by manual labour.

The dumper consists essentially of a rectangular framework which supports a cradle capable of holding an 80-ton wagon whilst rotating it through an arc of 150° and discharging the contents over the side without the necessity of opening any doors. When the wagon has rotated to a position where the coal begins to run, the side coincides with a large steel apron which is carried the full length of the dumper, so that the coal slides from the wagon without any fall to cause breakage. This apron has a holding capacity of 140 tons which equals the contents of four wagons, and so serves as a reservoir between the intervals of tipping. It narrows towards its lower end and concentrates the sliding coal towards the apex, where the mineral passes through a narrow shute in a constant stream of manageable proportion. Large rounded cobs of coal with a tendency to run wild from the wagon are brought to heel by a special baffle-plate placed for that purpose.

When the loaded wagon is pushed to its proper position on the dumping-cradle, it is clamped and held to the side of the same automatically, before hoisting and rotation commence, by a series of counterweights working in guides which form part of the dumper framework. These weights also serve nearly to balance the weight of the cradle when empty.

Operating the Dumper.—The operation of working the dumper is simple in the extreme, for the movements of securing the wagon to the cradle, hoisting and rotating them both until the coal is discharged, then lowering the empty wagon and unclasping it from the cradle, is started, accellerated, decellerated, limited and stopped by electrical device, the driver having only to move a master-switch to set going the cycle of operations.

The two hoisting drums are driven by two continuous current motors of 150 b.h.p., each working at 500 volts, and being interconnected through gearing to act as one unit giving a maximum rope-speed of 100 feet per minute.

These motors have to handle high peak-loads and a constantly varying demand for power, and also serve as dynamic brakes during the lowering of the empty wagon. Wide speed variations and absolute safety and control are necessary if the current should fail at any moment during operations. This safety is secured by powerful solenoid brakes capable of holding the load on the instant in any position it may be when the current fails. "Fool proof" devices are fitted to all terminal points. The rapidity of the automatic electrical movements allows a cycle of operations to be completed in a little less than two minutes.

The loaded wagons are delivered to the dumper from a gravity grid storage yard, whence they are released at the proper intervals by lifting the brakes. The gradient increases after passing the points at the neck, and the wagons gain sufficient momentum to climb some distance up the inclined track which forms the dumper approach.

At the foot of this incline the running wagon passes over a pit which is the "stable" where the "mule" or mechanical shunter stays when at rest. After the wagon has passed over the pit, the mule emerges behind the wagon and runs along a narrow gauge placed between the main track, until it overtakes the wagon before it comes to rest on the incline; and it completes the journey by pushing the wagon before it until the proper position on the cradle is reached. The same action serves to push the empty wagon off the cradle and start it down the opposite incline, where it runs by the acquired velocity to the grids where trains of empty trucks are made up.

The arrival of the loaded wagon at the spot desired on the cradle operates mechanism which automatically chocks the wheels in this position, and then releases the mule by disengaging a friction-clutch on the haulage drum, which action allows the mechanical shunter to be drawn rapidly back to its stable by counterweights acting on a tail rope.

The "mule" haulage drum is fixed in the dumper engine-house under the cradle, and it is driven by a 150 b.h.p. motor similar to the two previously described. The haulage rope passes from the drum and around bend sheaves leading to a line of rollers fixed between the "mule" track. The shock of contact between wagon and mule is absorbed by a specially designed spring head.

The total weight of the structure and machinery of the dumper is 260 tons and the cost, including erection, but excluding foundations, was a little over £20,000.

GRAB TRANSPORTERS.

The erection in 1901 of the first electrically driven travelling bridge transporter, designed for grabbing mineral from the holds of ocean steamers, marks the greatest improvement to date in the methods of unloading that class of material in bulk.

Whether further improvement will advance along the same lines as, for instance, the possibility of running a number of grabs in procession round an elliptical track or whether it will come from a different direction altogether remains to be seen. Suffice it to say, that the unloading of cargo in bulk will never equal the loading speed unless boats are built with a system of belt-conveyors as part of their internal economy. The experiment has been tried,* but it was in advance of its time and foredoomed to failure by the people who had its success most at heart.

Assuming that the loss of cargo space outweighs the advantage of rapid discharge by belt-conveyor, then the transporter-grab system will grow in capacity, size, and utility.

Types.—At present there is competition between two types, namely, the rope haulage system where the grab is operated by ropes driven from a fixed hoist, Fig. 2, Plate 3, and the rival system where the driver and hoisting machinery travel with the grab. The latter will probably triumph in spite of the higher cost, because the driver has at all times a complete view of the operations, and it is possible to arrange for more than one grab on the transporter.

The finest examples of the latter type, using single grabs, are—as far as the Author's own experience goes—the four transporters built to the order of the British Admiralty, Fig. 1, Plate 3. These machines weigh about 300 tons each; they are nearly 400 feet long and travel along double sets of rails whose gauge is 220 feet. They can grab coal from colliers and deliver it direct to the battleship or unload it into a storage yard of 100,000 tons capacity. These transporters are probably unique in the fact that they negotiate a curved track, and work along a wall built at an angle with the apex about midway of its length. The rate of unloading is 100 tons of coal per hour for each machine.

Han-Yeh-Ping Transporter.—The Author has recently installed in China a transporter whose two grabs and attendant machinery make a moving load of nearly 100 tons, Fig. 17, Plate 7. When it is considered that this load works on the end of a cantilever-arm nearly 150 feet length and that the structure has to stand also the shocks due to grabbing 10-ton loads at high speeds, then some idea may be formed of the size to which this class of machine is growing.*

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* S.S. "Pallion."

The transporter under review is designed for grabbing iron and manganese ore, limestone, coal and coke from the ship's hold and delivering it through storage bunkers, Fig. 19, Plate 7, to four blast-furnaces. The machine is equal in size to anything existing of its type, and the requirements, due to the rise and fall of the Yangtzse of over 45 feet, are unusually exacting.

When the river is at low level about 230 feet of foreshore is disclosed, so the site had to be piled and the foundations carried to 4 feet above high water level in such a manner that the front wall is now within 130 feet of water, deep enough to float the craft in use when the level of the Yangtzse is at zero. The distance of 130 feet is spanned by the two cantilever-arms of the transporter which has an overlay of nearly 150 feet from the face of the wall. The top of the four main columns which carry the girders at the centre are 137 feet and the bottom boom of the cantilevers 100 feet above low-water level, Fig. 20, Plate 7. The four bridge-girders are 37 feet deep at the centre and 282 feet long. The weight of the structure is 530 tons and the total weight of the machine 680 tons. The empty grabs weigh 7 tons each, and the combined force of the six electric motors employed is 500 b.h.p.

Description of Structure.—The transporter is constructed with two separate bridges, 50 feet centres apart, connected by wind bracing to act as one structural unit of great stability against wind pressure, Figs. 21 and 22, Plate 8.

The maximum load on the wall is about 800 tons, namely, 200 tons nearly on each main column. This wall is a substantial concrete-backed and stone-faced structure, but, as it is founded on the Yangtzse mud, considerable piling and grillage work was necessary to ensure stability. The river bank in the vicinity was afterwards pitched with slag to prevent erosion. The Author made a minute examination of the work after the first floods had subsided, and so far as could be seen, the precautions taken are all that is necessary. The levels of all the column bases were carefully checked also without finding any settlement.

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* For Electrical and other detail of this Transporter, *see* article by the Author in *The Electrician*, 31 Dec. 1920.

Each transporter-bridge is fitted with an underhung and revolving crane which travels with, and operates, a grab weighing 7 tons when empty, and 11 tons when full, Fig. 23, Plate 8. The weight of the hoisting, slewing and travelling mechanism, is nearly 38 tons each side, or when adding the two loaded grabs, about 98 tons altogether. As the grab and hoisting machinery are underhung from the travelling carriage, the former can slew round 360°, so that the two grabs working in co-operation can cover the whole area of a hatchway 60 feet long without moving the vessel. On smaller craft the grabs can work two hatches simultaneously.

The underhung portion is supported from the carriage by ball-bearings mounted on double trunnions designed to ensure that the weight is equally distributed over the four travelling wheels under all conditions of grabbing.

The hoisting, slewing and travelling machinery is driven by separate motors, and all three motions are controlled by one man who travels with the grab.

The power required is generated by a turbo-alternator and boilers gas-fired from the blast-furnaces. A rotary converter on the transporter site reduces the high-tension alternating current to 440 volts D.C.

The total cost of the plant was a little over £40,000, which means an overhead charge of threepence per ton for capital and depreciation costs on the proved capacity of the plant working day-time shifts only. By working three shifts of eight hours each, and cutting out the meal stoppages, the charge per ton could be considerably reduced.

Chinese Steel.—The Author is often asked how the steel produced by these Chinese works compares with the European product, so the following particulars may be of interest. Owing to conditions of war, the 75,000 field rivets required for the erection of the transporter had to be obtained out of England. Ingots were chosen from Hanyang Steel Works, heat No. 6,028, the chemical analysis of which gave the following results:—

	Per cent.
Carbon	0·15
Silica	0·03
Manganese	0·50
Phosphorus	0·03
Sulphur	0·048

After the rivet bars had been rolled, the static tests were carried out by the Author on a 50-ton "Buckton" machine with results as follows:—

Description.		Test No. 1.	Test No. 2.
Diameter of Bar . . .	Inches	0·873	0·877
Area of Bar	sq. inch	0·600	0·605
Distance between Marks . .	Inches	7	7
Bar Broke at	Tons	15·61	15·965
Ultimate Breaking Strain in Tons per sq. Inch	Tons	26·1	26·4
Ultimate Breaking Strain in Lb. per sq. Inch	Lb.	58,500	59,100
Elongation	Per cent.	31·7	32·7

The nature of the fracture was cupped, homogeneous and silky.

The Paper is illustrated by Plates 3–8, 2 Figs. in the letterpress, and is accompanied by an Appendix.

APPENDIX.

Belt-Conveyors.

FORMULA.

Where:—

A equals Approximate life of belt, in tons, conveyed
B ,, Cross section of load in square feet.
C ,, Cubic feet (maximum) conveyed per hour.
C′ ,, ,, ,, (average) ,, ,, ,,
D ,, Least diameter of driving pulley in inches.
H ,, Height the load is elevated IN INCHES.
L ,, Length of conveyor in feet.
P ,, Number of plys of cotton duck in belt.
R ,, Radius of curvature of belt in inches.
S ,, Speed of belt in feet per minute.
T ,, Tons (maximum) conveyed per hour.
t ,, ,, (average) ,, ,, ,,
W ,, Width of belt in inches.
Y ,, Specific gravity of material conveyed multiplied by 36.
Z ,, ,, ,, ,, ,, ,, ,, ,, constant.
H.P. ,, Brake Horse-Power required for horizontal conveyors.
H.P.′ ,, ,, ,, ,, ,, ,, inclined ,,
*H.P.″ ,, Maximum B.H.P. allowable for given width of belt and *single*-pulley drive.
*H.P.‴ ,, Maximum B.H.P. allowable for given width of belt and *tandem*-pulley drive.

CONSTANTS FOR Z.

36 For washed nut coal and sharp dry sands.
33 ,, Unsized coal containing no large lumps.
31 ,, ,, Rock ,, ,, ,, ,,
30 ,, ,, Coal with lump and small in equal volume.
28 ,, Rock ,, ,, ,, ,, ,, ,, ,,
26 ,, Coal containing nearly all lumps.
24 ,, Rock ,, ,, ,, ,,
24 ,, Coal all lump.
22 ,, Rock ,, ,,

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* H.P.″ and H.P.‴ govern the maximum length of any conveyor as a separate unit.

No. 1.

$$T = \frac{W^2\,Y\,S}{86{,}000}$$

$$\therefore\ S = \frac{86{,}000\ T}{W^2\,Y} \qquad W = \sqrt{\frac{86{,}000\ T}{Y\,S}} \qquad Y = \frac{86{,}000\ T}{W^2\,S}.$$

Example: How many tons of coal (specific gravity 1·5) can be conveyed (maximum) per hour by a belt 24 inches wide running at a speed of 300 feet per minute?

$$T = \frac{576 \times 1{\cdot}5 \times 36 \times 300}{86{,}000} = 108 \text{ tons per hour.}$$

No. 2.

$$t = \frac{W^2\,Z\,S}{86{,}000}$$

$$\therefore\ S = \frac{86{,}000\ t}{W^2\,Z} \qquad W = \sqrt{\frac{86{,}000\ t}{Z\,S}} \qquad Z = \frac{86{,}000\ T}{W^2\,S}$$

Example: How many tons of lump coal can be conveyed (on the average, per hour by a belt 48 inches wide running at 500 feet per minute?

$$t = \frac{2304 \times 1{\cdot}5 \times 24 \times 500}{86{,}000} = 482 \text{ tons per hour.}$$

No. 3.

$$\text{H.P.} = \frac{(W\,S + 22\ T)\ L}{280{,}000}.$$

$$\therefore\ L = \frac{280{,}000\ \text{H.P.}}{W\,S + 22\ T}.$$

Example: What Brake Horse-Power will be required to drive a belt 24 inches wide running at 300 feet per minute and conveying 108 tons of coal per hour over a distance of 100 feet?

$$\text{H.P.} = \frac{(24 \times 300 + 22 \times 108) \times 100}{280{,}000} = 3{\cdot}42 \text{ B.H.P.}$$

No. 4.

$$\text{H.P.}' = \frac{(W\,S + 22\ T)\ L + (30\ H\ T)}{280{,}000}.$$

Example: What Brake Horse-Power will be required to drive a belt-conveyor 48 inches wide and 191 feet in length when raising large lump coal to a height of 60 feet (about 20°) at an average rate of 482 tons per hour? The speed of the belt to be 500 feet per minute?

$$\text{H.P.}' = \frac{(48 \times 500 + 22 \times 723^{*}) \times 191 + (30 \times 720 \times 723^{*})}{280{,}000} = 85 \text{ B.H.P.}$$

* NOTE: In all cases the Horse-Power must be reckoned on the MAXIMUM and not on the *average* capacity of the conveyor. This amount of power will only be called for when the belt is carrying maximum load or starting a loaded belt up from rest. The average power consumed will, of course, agree with the average of the load carried.

No. 5.

$$\text{H.P.}'' = \frac{30\ \text{W S P}}{53{,}000}.$$

$$\therefore\ \text{W} = \frac{53{,}000\ \text{H.P.}''}{30\ \text{S P}} \qquad \text{P} = \frac{53{,}000\ \text{H.P.}''}{30\ \text{W S}} \qquad \text{S} = \frac{53{,}000\ \text{H.P.}}{30\ \text{W P}}.$$

Example: What is the maximum B.H.P. which may be exerted on an 8-ply belt 48 inches wide running at a speed of 500 feet per minute with a *single*-pulley drive?

$$\text{H.P.}'' = \frac{30 \times 48 \times 500 \times 8}{53{,}000} = 109\ \text{B.H.P.}$$

No. 6.

$$\text{H.P.}''' = \frac{30\ \text{W S P}}{43{,}000}.$$

$$\therefore\ \text{W} = \frac{43{,}000\ \text{H.P.}'''}{30\ \text{S P}} \qquad \text{P} = \frac{43{,}000\ \text{H.P.}'''}{30\ \text{W S}} \qquad \text{S} = \frac{43{,}000\ \text{H.P.}'''}{30\ \text{W P}}.$$

Example: Same as example No. 5, but with *tandem* pulley drive.

$$\text{H.P.}''' = \frac{30 \times 48 \times 500 \times 8}{43{,}000} = 134\ \text{B.H.P.}$$

No. 7.

$$\text{C} = \text{W}^2\ \text{S} \times 0{\cdot}026.$$

$$\therefore\ \text{W} = \sqrt{\frac{\text{C}}{\text{S} \times 0{\cdot}02592}} \qquad \text{S} = \frac{\text{C}}{\text{W}^2 \times 0{\cdot}02592}.$$

Example: What is the MAXIMUM load in cubic feet per hour that can be carried by a belt 24 inches wide and running at a speed of 300 feet per minute? N.B.—The volume includes the voids.

$$\text{C} = 576 \times 300 \times 0{\cdot}02592 = 4479\ \text{cubic feet.}$$

No. 8.

$$c = \text{W}^2\ \text{S} \times 0{\cdot}018.$$

$$\therefore\ \text{W} = \sqrt{\frac{c}{\text{S} \times 0{\cdot}0173}} \qquad \text{S} = \frac{c}{\text{W}^2 \times 0{\cdot}0173}.$$

Example: What is the AVERAGE load in cubic feet per hour carried by a belt 48 inches wide and running at a speed of 500 feet per minute when working on *large lump coal*?

$$c = 2304 \times 500 \times 0{\cdot}0173 = 19{,}930\ \text{cubic feet.}$$

NOTE: In examples Nos. 7 and 8 the constants 0·02592 and 0·0173 represent the two extremes of C and c. Intermediate constants to suit the class of material to be conveyed may be arrived at by the formula

$$\frac{\text{Constants for Z} \times 0{\cdot}02592}{36}.$$

No. 9.

$$B = \frac{C}{60\ S} \quad \text{and} \quad \frac{c}{60\ S}.$$

$$\therefore\ S = \frac{C \text{ or } c}{B \times 60} \quad \text{and} \quad C \text{ or } c = 60\ S\ B.$$

Example: What will be the sectional area—in square feet—of the load on a belt 48 inches wide when loading large lump coal (see example No. 8) at a speed of 500 feet per minute?

$$B = \frac{19{,}930}{60 \times 500} = 0{\cdot}66 \text{ square foot.}$$

No. 10.

$$R = \frac{W}{1{\cdot}3}.$$

Example: What radius of trough would be advisable on a conveyor-belt 48 inches wide?

$$R = \frac{48}{1{\cdot}3} = 37 \text{ inches radius.}$$

No. 11.

$$A = 567\ W^2.$$

Example: What should be the average life (expressed in tons conveyed) of a conveyor-belt 48 inches wide?

$$A = 567 \times 2304 = 1{,}306{,}368 \text{ tons.}$$

Similarly, the life of a 24-inch belt would be 326,592 tons.

No. 12.

$$D = \frac{6\ P + W}{2}.$$

Example: What should be the least diameter of the driving pulley for a 6-ply belt 24 inches wide?

$$D = \frac{6 \times 6 + 24}{2} = 30 \text{ inches diameter.}$$

A table of data worked from the foregoing formula is given at the end for handy reference.

BUCKET-CONVEYORS.

For calculating the Brake Horse-Power required by bucket-conveyors the following formula—which the Author has tested by actual experience to be a sufficiently reliable guide to any but those requiring more expert knowledge—may be useful.

$$\text{B.H.P.} = \left\{ \frac{\left[L\ S \left(\frac{X}{Y} \right) \right] + (H\ W)}{33{,}000} \right\} + B.$$

Where :—

L equals Total length of chain *on rail.*
S ,, Speed of chain in feet per minute.
X ,, Average weight in lb. per foot-run of chain, including buckets and load.
Y ,, 11 for 6-inch wheels; 10 for 5-inch wheels; 9 for 4-inch wheels.
H ,, Height in feet the load is elevated.
W ,, The weight in lb. elevated per minute.
B ,, Number of pairs of bend wheels used, including tumblers.

NOTE : Some discrimination is necessary with B. In small plants $+ \frac{B}{2}$ would be more correct. In large plants + 2 B would be better.

Example : What Brake Horse-Power would be required to drive a chain of buckets 620 feet (total length of chain) for elevating 40 tons of coal per hour to a height of 60 feet. The bucket chain to be fitted with 5-inch trod wheels, to run at a speed of 40 feet per minute and discharge the coal into bunkers at any point under the top portion of the chain. Assume the weight of chain and buckets to be 84 lb. per foot and the load equal to 36 lb. per foot of chain. Four sets of bend wheels required besides the driving tumblers ?

$$\therefore \text{B.H.P.} = \left\{ \frac{\left[500^* \times 40 \times \left(\frac{120}{10}\right)\right] + (60 \times 1440)}{33{,}000} \right\} + 5 = 14{\cdot}9 \text{ B.H.P.}$$

* NOTE : It will be noticed that although the chain has a total length of 20 feet, yet only 500 feet is supported by rails.

AERIAL ROPEWAYS.

For calculating the h.p. required to drive an Aerial Ropeway the Author gives the empirical formula which follows. It has been devised from actual practice, but must be used with caution because so many complications are likely to occur on different sites.

$$\text{H.P.} = \frac{\left[\left(\frac{W}{60}\right) S\right] \pm (H\ W)}{33{,}000}.$$

Where :

W equals Weight of mineral in pounds on ropeway.
S ,, Speed of buckets in feet per minute.
H ,, Height in feet raised (or lowered) per minute.

Example :—

What h.p. will drive an aerial ropeway 24,000 feet between terminals, The ropeway to transport 40 tons per hour when travelling at 400 feet per minute. Assume a total fall of 480 feet?

$$\therefore \text{H.P.} = \frac{(1{,}494 \times 400) - (8 \times 89{,}600)}{33{,}000} = -3{\cdot}6 \text{ H.P.}$$

In other words, the ropeway when fully loaded has a surplus of 3·6 h.p. after moving its own load by gravity.

But it will be necessary at times to work the ropeway without load. This would be the case when starting up a new plant and after repairs, and these contingencies have to be considered when designing the drive. The power required in this case is obtained from the first part of the formula namely :—

$$\text{H.P.} = \frac{\left(\frac{W}{60}\right) S}{33{,}000} = \frac{\left(\frac{89{,}640}{60}\right) 400}{33{,}000} = 18 \text{ H.P.}$$

It should be noted that the formula given is for buckets running on ball-bearing carriages. With plain bearings considerably more power would be required.

Belt Conveyors.

Data for selecting suitable size of Conveyor, based on the preceding formula and conditions as follows:—

COAL: specific gravity 1·5; voids 42·3 per cent; weight per cubic foot 54 lb.; volume 41·48 cubic feet per ton.
ROCK: ,, ,, 2·8 ,, 42·3 ,, ,, ,, ,, ,, ,, 101 ,, ,, 22·2 ,, ,, ,, ,,
IRON ORE: ,, ,, 4·0 ,, 42·3 ,, ,, ,, ,, ,, ,, 144 ,, ,, 15·55 ,, ,, ,, ,,

Width of belt, in inches	24	30	36	42	48	54	60
Speed of belt, in feet per minute	300	350	400	450	500	500	500
Maximum capacity, in tons per hour, when loading mixed coal, no large lumps	108	198	326	500	723	915	1130
Average capacity, in tons per hour, when loading lump coal	72	132	217	333	482	610	754
H.P. required for each 100 feet of conveyor	3·5	5·3	7·7	10·7	14·3	16·9	19·6
Additional H.P. required for each 10 feet the load is elevated	1·4	2·6	4·2	6·5	9·3	11·8	14·6
Maximum capacity, in tons per hour, when loading mixed rock, no large lumps	203	372	609	932	1353	1712	2114
Average capacity, in tons per hour, when loading lump rock	124	226	371	568	825	1044	1290
H.P. required for each 100 feet of conveyor	4·2	6·7	10	14·1	19·2	23·1	27·4
Additional H.P. required for each 10 feet the load is elevated	2·6	4·8	7·9	12	17·4	22	27·2
Maximum capacity, in tons per hour, when loading mixed iron ore, no large lumps	290	527	868	1330	1930	2441	3000

Average capacity, in tons per hour, when loading lump iron ore	177	322	530	812	1178	1492	1842
H.P. required for each 100 feet of conveyor	4·9	7·9	12	17·2	23·7	28·9	34·3
Additional H.P. required for each 10 feet the load is elevated	3·7	6·8	11·2	17	24·8	31·4	38·6
Extra H.P. required for each fixed tripper	1·4	1·8	2·4	3·2	4	4·5	5
Extra H.P. required for each movable tripper	1·8	2·3	3	4	5	5·6	6·2
Size of largest lumps that can be conveyed	6-inch cubes	8-inch cubes	10-inch cubes	13-inch cubes	16-inch cubes	18-inch cubes	20-inch cubes
Maximum width of opening for feed-hopper	15 inches	20 inches	24 inches	30 inches	36 inches	40 inches	45 inches
Approximate life of belt, in tons	350000	500000	700000	1000000	1300000	1600000	2000000
Maximum H.P. advisable on 8-ply belt with single-pulley drive	33	48	66	85	110	122	136
Maximum H.P. advisable on 8-ply belt with tandem-pulley drive	40	60	81	105	135	150	168
Maximum length for horizontal conveyor, loading coal, tandem-pulley drive	1143	1132	1050	982	944	888	860
Maximum height coal can be elevated, by one unit, with 8-ply belt, inclined 18°	160	140	120	106	97	87	79

NOTE: (*a*) For tropical climates, add 10 per cent to H.P. required on electric motors.

(*b*) For rough-cast gearing, add 10 per cent to H.P. required.

(*c*) For conveyors taking less than 10 H.P., add 10 per cent. to H.P. required.

Discussion in London, 21st January 1921.

Mr. F. T. Parker, in the absence of the Author, introduced the Paper. He regretted that the Author was not present, because there were points in the Paper and in the Appendix with which he was not in accord, of which the Author was aware. The opinions expressed were based upon the Author's experience without reference to or collaboration with any parties whatsoever. Some Members present might take exception to some of the statements. Business unfortunately interfered with his being able to discuss the Paper fully with the Author, but he was familiar with some of the plants, although not those described.

Mr. Parker exhibited a series of slides illustrating the Paper.

The President proposed a vote of thanks to the Author for his valuable contribution. The life work of the Author had been on the subject, which had not been before the Institution since 1906. He would point out that the Paper dealt only with the loading of ships, and a complementary subject was the unloading of ships, on which steps had been taken to obtain a Paper.

Mr. A. Binns regretted that the Author was unable to be present at the Meeting. He had said a good many things in the Paper which perhaps scarcely came legitimately within the scope of the title; and certainly there were many things which did come within the scope of the title that were not said in the Paper. That was all to the good, because it gave an opportunity of introducing matter not explicitly referred to in the Paper. The Author dealt exclusively with the loading and unloading of bulk materials. That of course was an exceedingly important subject, but a comparatively small section of the total work of loading and unloading ships. As a dock engineer he (the speaker) was interested in the mechanical loading and unloading of ships from the widest point of view.

On the first three pages of the Paper the Author remarked on the economic aspect of the question of labour-saving appliances, and the way in which they could be used to reduce the ultimate cost of commodities to the community, and that was what engineers were aiming at in all their work. The war, of course, transformed industry. Rates of pay had increased enormously, hours were shortened, and overtime was worked only at very extravagant rates, and all these factors tended to reduce the efficiency of the terminal facilities in the ports. He had heard expert evidence to the effect that quay accommodation to-day was 20 per cent less efficient than it was in pre-war days, which naturally tended to increase congestion all round. The dock on which he was engaged was in course of construction, and would cost over £4,000,000; the cost of its mechanical equipment for handling cargo would certainly not be more than 10 per cent of that figure, and he felt —and that was the real point that he wanted to make—that in considering the question of the adoption of labour-saving appliances, one very often took far too narrow a view. For example, the source of revenue of a dock company was almost entirely from dock dues or river dues or dues on goods, and to a very small extent indeed was the revenue derived from direct charges made for the use of special plant; but if the use of that special plant would increase the tonnage turnover on the whole fabric for twelve months and therefore give increased tonnage dues, obviously the very small expenditure on that special plant might be justified, although the direct charges might be altogether unremunerative. He was exceedingly interested in the practical information given in the Paper, in the empirical formulæ, and especially in the notes with regard to conveyor-belts. He had had difficulty himself in writing a satisfactory specification for conveyor-belts and an equal difficulty in making a satisfactory comparison of tenders.

With regard to the handling of general cargoes, the most universal appliance—and a wonderful appliance—was the ordinary ship's winch and derrick, and he supposed it did more work than all the expensive pieces of plant put together. Those who watched, from day to day, the expert way in which stevedores could handle

(Mr. A. Binns.)

ships' winches and derricks, and could load and unload cargo, were filled with admiration. He was afraid at times they had served as a deterrent in keeping dock companies and other authorities from providing more up-to-date plant on the quay. With regard to conveyors, their use for general cargo was an exceedingly difficult subject. In his opinion it could be only hoped to apply conveyors for general cargo where packages of something like uniform dimensions and weights were being dealt with—that was to say, in connexion with ships working on a particular trade. Such appliances might be adopted for the tea trade or the meat trade. The Port of London Authority recently constructed at the Royal Albert Dock a fine up-to-date cold store which had cost over £400,000, and the cost of the handling appliances in that case amounted to something like 10 per cent of that figure. These conveyors took the meat from the deck of the ship and placed it in the cold sorting floor, where longitudinal conveyors transported it a thousand feet; portable conveyors then took it off and distributed it to the various stowages according to marks, or across to inclined conveyors which took it up to the cold store proper, where distribution was done by internal and external lifts. There were also lowerers in the cold-sorting floor for dealing with cargo going either to craft or to road or to rail. That was a conspicuous example in which it was possible to discharge, from one hatch with one machine, carcases at a rate of about 1,400 per hour with a considerable reduction in the working costs.

With regard to quay cranes, the new dock to which he had referred was being equipped with 3-ton electric cranes of 60 feet radius and 70 feet drift. His own feeling was that quay cranes were approaching the limiting dimensions for which they were economical and practical, and he felt that very little progress had been made on the general lines of the design of quay cranes for a century. At the docks they had been adapted to all sorts of power and placed on pedestals and bogies, but the crane to-day was in essential design on the same lines as one hundred years ago. The sets lifted by ordinary quay cranes averaged about a couple of tons, and the moving parts when slewing weighed 20 or 30 tons.

FIG. 24.—*Beam supported at both ends Sagging under its own Weight.*

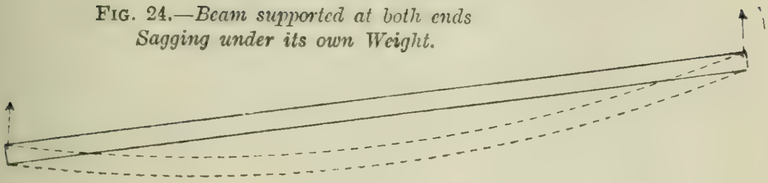


FIG. 25.—*Boom* (Walker) *with Load on Cable.*

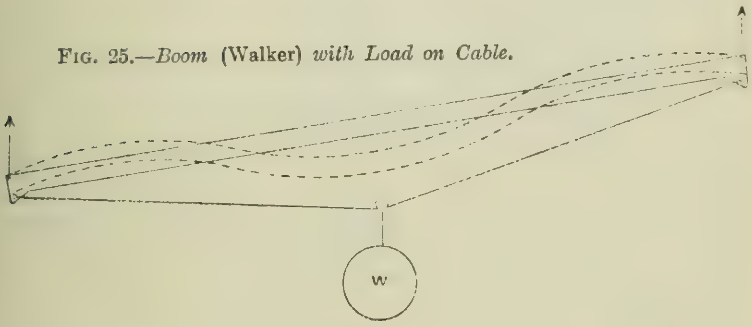
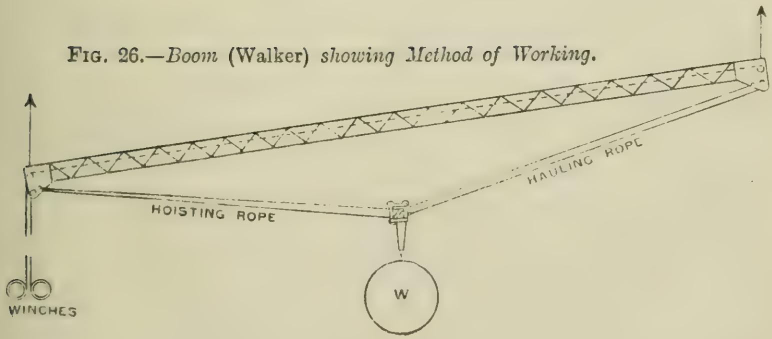


FIG. 26.—*Boom* (Walker) *showing Method of Working.*



(Mr. A. Binns.)

FIG. 27.—*Beam supported at Centre, Hog-backing under its own Weight and Load on Cable.*

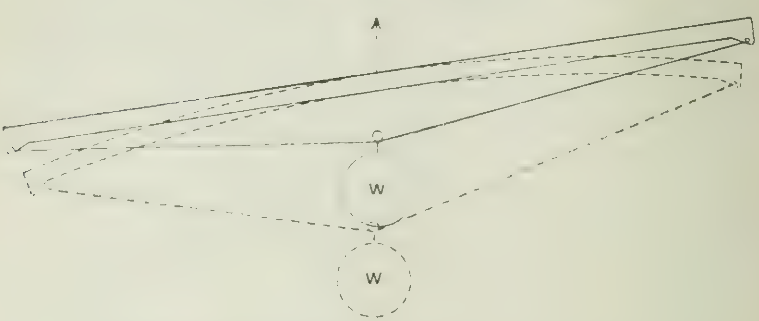


FIG. 28. *Boom* (Walker) *hinged and supported at Centre with Overslung Cable.*

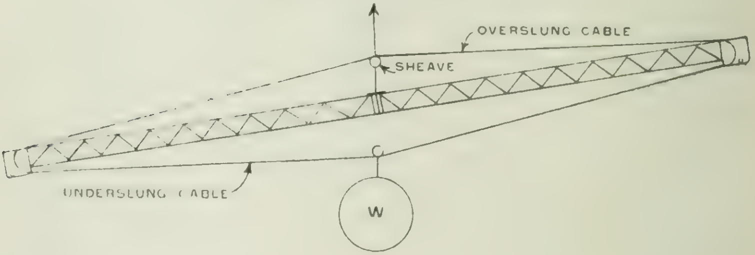
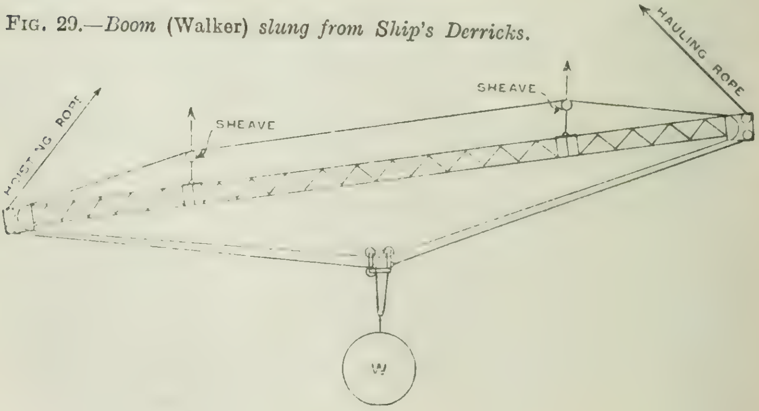
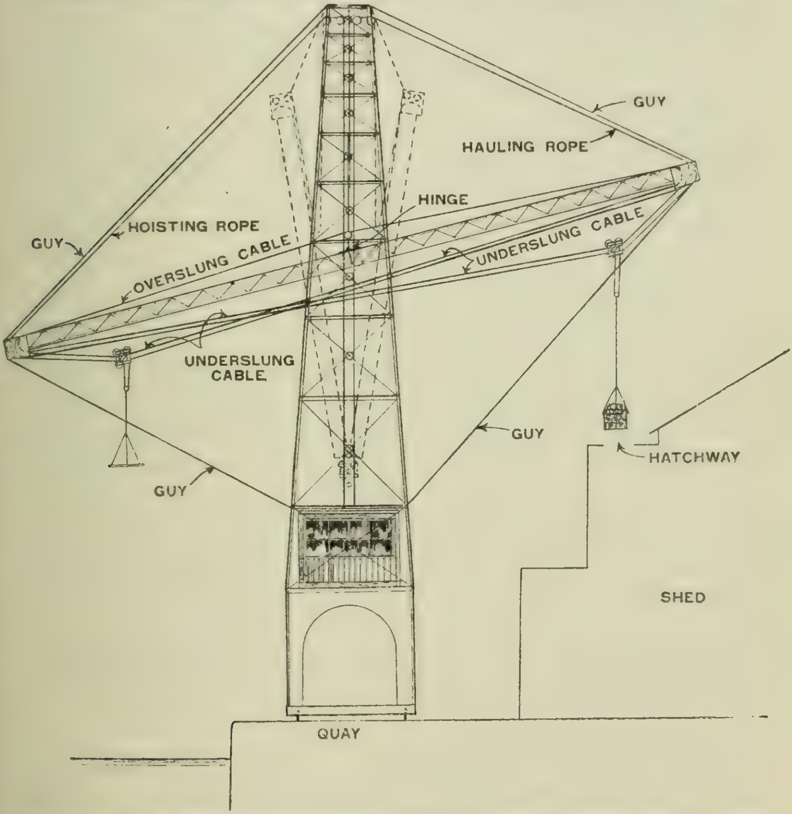


FIG. 29.—*Boom* (Walker) *slung from Ship's Derricks.*



In the transporter in China described in the Paper, there was a moving load of 100 tons dealing with a maximum useful load of about 8 tons. Those considerations had prompted a colleague of his, Mr. Walker, to devise a crane which was described in *The Engineer* of 24th December last, and he would show one or two illustrations in connexion with it. He hoped the pictures would stimulate some crane-makers to design a crane of a different class from what had been previously used. During the War the Port Authority had to build reinforced concrete sheds and, to save timber for shuttering, they were designed with premoulded beams which

FIG. 30.—*Proposed Duplicate Quay Crane with Folding Boom* (Walker).



(Mr. A. Binns.)

had to be handled. As they weighed over 3 tons, it was a very difficult thing indeed to place them in position in a building of 120 feet span without the adoption of a special crane.

(Mr. Binns exhibited slides showing large and small cranes, with diagrams; also a slide showing the application of a cable way and a sketch of Mr. Walker's idea of the quay crane with the boom suspended from a tower in the middle and working from the shed to ship; some of these are reproduced in Figs. 24 to 30 (pages 113–5) and Fig. 31, Plate 9.)

Continuing, Mr. Binns said one point he wished to make about the girder shown in Fig. 31, Plate 9, was that it was 150 feet long and only 5 feet deep, and was carrying a load of 3½ tons in the middle. No Telfer girder could do it with anything like that weight of construction.

The Author raised the old question of hydraulic *v.* electric operation in connexion with the various machines (page 93), and gave some figures of relative efficiencies. He still believed that hydraulic and electrical power had each its own field. At the new dock of which he had spoken, hydraulic power was used for lock-gates and sluices and swing bridge, and electrical power for the quay cranes and the bascule bridge.

The Author referred to four types of plant, namely, the aerial rope-way, the conveyor, the dumper, and the grab transporter, and gave various figures for capital costs, capacities, and, in some cases, working costs. It would add very greatly to the value of the Paper, although the plants were not comparable with each other, if the Author would give a tabular statement of the figures.

Mr. C. KEMBLE BALDWIN (Member of the American Society of Mechanical Engineers) said it was a great pleasure to be received by the Institution as a Member of the American Society. He had spent about twenty-five years in the manufacture of belt-conveyors, so there were a few points he would like to mention. The Author complained of a lack of data with regard to belt-conveyors. There had been a considerable literature on that subject published in the United States, and he had had the pleasure of reading a Paper before the American Society of Mechanical Engineers in 1908, in which he presented capacity tables, power formulæ, and so forth, and those figures had been reproduced in many handbooks ; and in the recent American Mechanical Engineers' handbook, edited by Professor Marks, of Harvard, there were 82 pages of data on hoisting and conveying machinery. Over 52,000 copies of that volume had been sold, so that no doubt many members of the Institution had copies. Possibly the Author had not seen it.

The Author mentioned (page 82) a belt-conveyor 30 inches wide, of 8-ply cotton duck, faced and filled with rubber, and in the Table (pages 108–9) he gave the maximum length for horizontal conveyors loading coal, tandem-pulley drive, for a 24-inch conveyor, as 1,143 feet, that being based on an 8-ply belt, and on a 60-inch belt a maximum length of 860 feet. In practice those figures would be reversed, as the wider belt could be built in much longer lengths than the narrow one. The Author had not taken into consideration the fact that a 24-inch belt, 8-ply, would not trough, that the maximum belt which would trough properly was about 6- or 7-ply. The Author's figure of maximum length being based on an 8-ply belt he believed was incorrect. As a matter of fact, a 60-inch belt handling coal could be built up to 1,500 to 2,000 feet. There were in operation at Baltimore, U.S.A., at the coal loading docks of the B. & O. railroad, four conveyors 60 inches wide, 1,000 feet long, each handling 2,000 tons of coal from the cars to the ships. It was possible with that plant to load four ships at one time at the rate of 2,000 tons per hour. That was by no means the maximum length to which the conveyors could be built, but it was the maximum length the job called for.

In the matter of capacity, the Author rather limited the capacity for coal to 1,130 tons for a 60-inch conveyor, while in the particular case he was referring to they were handling daily 2,000 tons. He also had in operation a single conveyor handling crushed stone at the maximum rate of 3,000 tons per hour (average about 2,000 tons per hour), lifting the material about 60 feet in the air from the bottom of the crusher to the screens. That plant was on Lake Michigan, where a metallurgical stone was made at an average rate

(Mr. C. Kemble Baldwin.)

of 2,000 tons per hour, the material being screened, crushed, washed and put into open storage piles and reclaimed from those piles through concrete tunnels by belt-conveyors, three tunnels being under each pile. The capacity of the conveyor in each tunnel was 1,500 tons per hour, ships being loaded at the rate of 4,500 tons per hour. From that plant considerable material was shipped in self-unloading boats, the Company having three boats of the Lake type carriers with engines in the stern. The boats were 550 feet long and had a capacity of 11,500 tons. The conveying machinery was built into them, so that they would unload themselves in 5½ hours, the average capacity during the unloading time being about 2,000 tons. Those ships were built for the purpose of supplying plants on the Great Lakes with limestone, which was the only product they got by ship, and consequently unless the ship could unload itself, the stone could not be received by water. That particular stone was a deposit of 98 per cent carbonate of lime, and 7,000,000 tons were shipped by the plant in 1920 in a period of open navigation of about seven months.

With regard to the question of dumpers, the Author seemed to question some of the capacities obtained in the United States, and said (page 94) that the figure gave an average of nearly 49 tons of coal per wagon. The average car in the United States handling coal now was a 50-ton car, and most of the cars that went to the dumpers on the seaboard carrying coal for export were larger than 50 tons; the bulk of those now being built was 90 tons, and the Virginian Railroad had built 1,000 120-ton cars net weight. They also operated car-dumpers which dumped two cars at one time, at the rate of forty dumps per hour, or eighty cars per hour. The 120-ton cars had twelve wheels, were about 50 feet over bumpers, 11 feet high and 10 feet 6 inches wide.

Mr. J. H. ANDERSON suggested that the Author had put forward a few particulars which were open to friendly criticism—not from the point of pulling the Paper to pieces, but from the view of constructive helpfulness. First of all, he suggested that to an engineer the design relating to the size and capacity of bulk-handling plants was not an engineering problem of very great magnitude. The problem, if any, was to convince the non-technical people who controlled finance that the cutting down of prices in capital outlay, although at first sight it might appear to be very clever, in the long run often made the working costs so high that they could not compete with better plants. Providing conditions warranted it, the speed of loading and discharging vessels with bulk cargoes could easily be made much faster, but, in this country, engineers were hampered very much owing to being the pioneers in that class of trade. They started with what would to-day be called very small units, but when those units were brought out no doubt they were a big jump, so much so that a huge amount of capital had been expended in the fitting up of collieries with small tubs, small hoisting gears, small wagons to take the coal to the drops, small ships to convey the material by sea, and even less than twenty years ago much of that coal was discharged by hand, even on the Thames.

From those gradual growings the railways had been standardized with what the Author said some one called " matchboxes on wheels," which he personally agreed was the case for bulk cargo operation, except a few 40-tonners in the north. He suggested that British engineers were the pioneers, and thus other people who did not begin to develop their countries till nearly a century later had had all the experience to go upon, and had made that their starting-point. Thus they were to-day working their easiest procured coal in their shallow pits (and even in huge quarry excavations) with huge coal-cutting machinery, mechanically loading large pit-tubs at the working face, gathering them by electric gathering engines, and assembling them inside many of the hillside mines into trainloads, which were hauled by large electric locomotives to the place of preparation for market. Those particular coals gave a high output, to deal with which, high-capacity wagons were used, and some of the latter held over 100 tons. They were constructed so that doors were opened on the bottom or at the side, whereby all the coal would gravitate out of the wagon into hoppers, or in other cases, where the height did not allow for that, they were elevated and tipped. To meet the quick delivery of coals from those wagons, ships were

(Mr. J. H. Anderson.)

specially designed for the purpose, and on their discharge high-capacity machinery was employed. The members could compare the British methods with those he had mentioned, the details of which were too numerous to discuss at that Meeting, but there were two Papers* on the subject read by the speaker before the Institute of Marine Engineers.

He hardly agreed with the Author that the principal cause contributing to the past success of this country in steel and iron was transport alone. Transport was only one unit of it, although no doubt it was a very prominent one-to-day, but in the past there had been an abundance of ore and coal in the same locality and therefore furnaces had been erected there. Iron was made long before coal was used, and districts like Sussex, Forest of Dean, Kent, etc., where wood was plentiful, were in those days the home of the iron trade. Industry must go to fuel, and even in the days to which he had just referred, it was recorded that iron manufacture went to Ireland owing to the thinning out of some of the English woods that supplied the fuel. He thought that a similar thing was occurring to-day in this country. Fuel was becoming more difficult to procure, its cost was almost prohibitive, and our opportunities had been thrown away. America, China, Germany and other countries that possessed more coal than this country, and whose coal was much more easy and cheap to produce, would gain from our past experience and start on a scale that would put us in a difficult position to compete with them, unless the problem were attacked in every detail from its source to the consumer.

With regard to the Sebabna plant, one would like to see a diagram of the transport system before discussing it, but it might be of interest to state that many of the hillside mines in America had to adopt what were termed "retarding conveyors," which in most cases were round disks of wood or plate bolted to an endless wire at every few feet. Many of those were delivering coal up to 300 tons per hour, and, of course, most of the power was utilized for braking or governing the speed, a very small motor being sufficient for that purpose. He agreed with the Author regarding the angle of repose of material, but why was not that considered in the design of the plant ? Would a chain scraper get over the Author's difficulty ? It required very little effort to create an avalanche of that material held up ; in fact, the release of a small piece, sometimes done by throwing a lump down the incline, would often start hundreds of tons, so that it would continue running to the spout. Therefore a small endless chain of a portable type might overcome the difficulty. Another mistake seemed to have been made by excavating the hopper 16 feet too deep. Surely it would have been cheaper to build a retaining wall for the 16 feet on the top rather than cut the whole area out of rock. In fact, the plant seemed to have been designed purposely to neglect gravity, by lowering the material some hundreds of feet and then having to raise it up by mechanical means· The hopper storage at the mooring might have been built of ferro-concrete of such a height that the top would be the anchorage for the ropeway transport, tipping the material along a hopper the full length of ship hatches ; and all holds could be loaded simultaneously by gravitating the ore through a spout opposite each hatch. Thus no power would be required and very little labour involved, the speed of loading being increased by the number of hatches in the vessel—mostly four, but often five or six. The structure would also form an excellent place for mooring vessels. He mentioned it because there seemed to be quite suitable material on the site for making concrete aggregate.

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* Trans. Inst. Marine Eng., 1919, vol. xxxi.

With regard to the trimming of the cargo, the specific gravity of the material was such that only a small part of the hold space was needed. As those ships were usually coal-carrying vessels, there should be no hand-trimming needed with ore. Many colliers were self-trimming, for which a special rate was given on the loading.

With regard to the speed of loading there was no novelty in that, even if 800 tons per hour was reached. There were many plants that had been in operation for several years putting bulk cargo into more difficult places at a much higher loading rate. The Author said he witnessed 660 tons loaded in fifty-five minutes.

(Mr. J. H. Anderson.)

Could he state how long the vessel was alongside the structure? The total tonnage could then be divided by the number of hours, which would give the working average per hour.

With reference to the vibration of the structure, surely the release of half a ton of material at regular times at the long leverage mentioned would set the thing in motion and gather a little momentum each time until it balanced the resistance of the structure. He agreed with the Author that belt-conveying would have been better than using a huge chain of buckets.

He thought the Author was a long way behind so far as his records of loading were concerned; 800 tons for an hour and 7,000 tons for a working day of ten hours had been exceeded by a discharging plant, and the Author stated that discharging would never be so fast as loading. The Author's suggestion of future improvements, such as running a number of grabs round an elliptical track, was not a novel idea, as it was already in use, but the obstruction on vessels, such as masts, funnels and deck-houses, had to be taken into consideration, including the cosmopolitan shipping that had to be dealt with.

The example of the "Pallion" was also out of date, and vessels of that kind of arrangement might be stated to be giving satisfaction in many places in the States, principally for discharging ore and limestone. He might mention the "Herman Sauber," Fig. 32, Plate 9, also built by Messrs. Doxford to discharge 1,200 tons of coal per hour, which the Germans used for ore transport during the War, incidentally stiffening the hopper bottom with angles, thus obstructing the flow of coal since that time. The vessel, however, had been of use to this country since it was handed over.

The weight of empty grab, in comparison with the weight of material carried by the Han Yeh Ping transporter, was 7 tons grab to lift 4 tons of material. He trusted the Author did not claim that as an economical point, as the whole plant would have to be strong enough to stand that very heavy non-earning load, which was always a charge, whether the grab were full or empty. There were many grab plants lifting 2½ tons of coal or ore having grabs of the same weight as the material lifted. It must also be taken into consideration that in practice if the size of grab were increased, the ratio of its weight to the load lifted could be reduced. In addition to the working charge, there was also the increased cost of the heavier machine and foundations designed purely for the non-earning load. He saw no reason why the grab should exceed 5½ tons, and why it should not grab 5½ tons of material if it were properly designed. He suggested that future improvements in rapidity of loading and discharging would take place when all the units employed, from the source of the material to the consumer, were designed with a view to increasing their size, but it must not be forgotten that even to-day there were many ships, down whose hatches one could not get a 2-ton grab.

(Mr. Anderson exhibited a series of slides illustrating his remarks. Two are reproduced in Figs. 32 and 33, Plates 9 and 10. The latter showed a cutting and loading machine, which undercut the coal at the bottom, sheared each side of this vertically, broke down the coal with mechanical picks, gathered and elevated it to a swivelling conveyor for delivery to a storage hopper. Thirty tons per hour had often been done with this machine, averaging throughout the day. The average output in British collieries was about one ton per man employed.)

Mr. F. G. MITCHELL said that it was fairly evident the Author's observations on the plants described were from the point of view of the Works Engineer, and not from that of the designer.

With regard to the belt-conveyor at Durban various figures were given, and if they were worked out it would be found the horse-power he mentioned as actually driving the belt was very much below the horse-power given in his own Tables, and it would be interesting if some explanation of that discrepancy were given. He himself believed the explanation was that the figures in the Table represented the horse-power required from ordinary idlers, while the plant described was fitted with ball-bearing idlers. It would be a considerable help to the understanding of the different Tables if the spacing of the idlers was given, the diameter of the rollers and the kind of idlers used, because those items affected the horse-power very much.

(Mr. F. G. Mitchell.)

One of the earlier speakers had mentioned the tests of the belt. The Author said that the rubber cover should stand an elongation of 300 per cent before breaking, but he did not mention that it was very important that, when the rubber cover was stretched, it should contract again to its original length. The Author referred to the duck of a belt-conveyor, and said (page 83): "When examining a sample of a rubber belting, the cotton duck should be exposed so that the number of yarns can be counted in the warp and filler." He believed the modern belt-conveyor was composed of duck which had very much stronger yarns running in the direction of the belt than across, in order to give very much greater tensile strength for the belt in that direction than in the cross-section, and to allow easier troughing for the same weight of conveyor.

All the conveyors and transporters mentioned in the Paper, it was evident, were designed under pre-war conditions, when labour was very much cheaper than it was at present. The plant at Devonport he understood required sixteen men to operate it during the day and eight during the night, and to-day the same capacity would be looked after by three or four men at the outside. The storage at Devonport actually required more men than the unloading.

He had been extremely interested to hear Mr. Baldwin's remarks about American practice. It was generally believed that American practice was very much ahead of that in this country, mainly because the engineers in this country were afraid of big capacities and of high speed. He thought this country could equal the Americans, if only people could be persuaded to buy the plants and use them at the higher speeds, which were really safe speeds. (*See* page 151.)

Mr. W. S. EDWARDS said that he wished thoroughly to endorse the later remarks of Mr. Mitchell in regard to the necessity for English engineers accustoming themselves to the high speeds which were required in connexion with some of the larger unloading plants now being contemplated. The Author assumed that there was a lack of technical data in engineering handbooks. There had recently been an undoubted tendency on the part of British publications to devote considerably more space to that important subject, as the question of the mechanical handling of materials in this country was becoming increasingly important every year. At the same time it must not be forgotten that a great deal of very valuable data already existed both on the Continent and in America to which due regard should be paid.

With regard to the Author's remarks as to bucket-conveyors, he was evidently not aware that self-discharging steamers were at present in operation in Middle West America, in which a bucket-elevator was installed, capable of continuously dealing with 2,000 tons of broken limestone per hour.

On the question of Stauffer lubrication, it had been the speaker's experience that oil-lubricated trod-wheels gave excellent service for the handling of coal and other non-abrasive materials, but for the handling of stone or Chilian nitrates and other abrasive materials, Stauffer lubrication became almost a necessity; and, provided suitable means were taken to prevent the lubricators from becoming loose in action, and that they were of large capacity, thereby avoiding the necessity of frequent filling, his experience was that they represented the best practice.

The Author mentioned the rated capacity of the bucket-conveyor as being 800 tons per hour, and it would be of interest to know if that figure had been reached since the installation of the automatically lubricated bucket-wheels. It was not clear from the Author's statement with regard to the oscillations of the cantilever (page 81) whether the swaying movement which occurred was equally apparent, both during the time the plant was running and when it was at rest. The $2\frac{1}{2}$-inch swaying referred to would appear to be due to the heavy load placed at the end of the cantilever, rendered necessary by the telescopic arrangement of the bucket-conveyor. The Author remarked that a 48-inch belt-conveyor, travelling at 400 feet per minute, carried a heavier load than the 800 tons for which the bucket-conveyor was designed. In view of recent experience, he thought it was quite evident that a far larger load could have been carried in that way, always provided the circumstances attending the other details presented no obstacle.

(Mr. W. S. Edwards.)

With regard to guaranteeing the life of a belt, it seemed reasonable to ask for a guarantee of the life of conveyor-belts, but owing to the many circumstances attending the operation of the belt, which were entirely outside the control of the belt manufacturer, it was impracticable to do more than give instances based on practical experience as to the life which should be expected. With reference to speeds (page 85), in many instances it was not possible to flatten the angle of the belt gradually, as suggested, and the difficulty to which the Author referred could usually be overcome by the interposition of suitable feeding apparatus, designed to take the shock of the falling material off the belt, and to assist in changing its direction of flow and feed it evenly thereon at considerable initial velocity. He did not agree as to the necessity for driving inclined conveyors through worm-gearing in order to prevent their running back, as by the application of a very simple check mechanism the running-back could be entirely overcome. As to the spillage at bend-pulleys, he was afraid that the remedy was worse than the disease. Any attempt to use troughing idlers round a bend must inevitably produce heavy stresses on the edges of the belt, and consequently shorten its life. The best method was to make use of properly adjusted skirtboards.

Brief reference was made to the weightometer, and it would have been interesting if the Author could have given some details of the degree of accuracy attained by that method of weighing, which undoubtedly possessed features that lent themselves for easy adaptation to belt-conveyor systems. In regard to the relative advantages of belt-conveyors as compared with dumpers, that question would undoubtedly come very much to the fore in the near future. The majority of the existing coal staiths would be quite incapable of dealing with the large-sized wagons, and he thought the cost of building new staiths at high capacity would be almost prohibitive, compared with the possibilities of converting existing staiths into belt-loading plant, as had been already done in one instance. The Author stated that the unloading of cargo in bulk would never equal loading speed unless self-discharging vessels were used. It might be of interest to know that unloading grab-transporters were now in operation, whereby an unloading speed of 1,000 tons per hour, with one transporter, was not unobtainable. Furthermore, self-discharging vessels equipped with a complete system of belt-conveyors had for some time been in regular use in the United States, discharging at the rate of 2,000 tons per hour.

Mr. F. T. PARKER said the Author was a friend of his, and it would therefore be ungracious first to introduce his Paper and then subject it to criticism. He was of the opinion that the Author had underestimated the capacities of the belts, and overlooked other factors to which Mr. Baldwin had partly called attention. His own experience, backed by data in his possession, led him to conclude that the Author was too conservative, but it was to be borne in mind that the Table was based upon results derived from empirical formulæ. For some fifteen years or more the Author had been actively engaged as an engineer in the field on a variety of belt-conveyor and other plants for handling loose material. A field engineer was not always furnished with the whole of the technical information relating to a contract. He had his plans and instructions, and his work was to supervise erection, start and tune-up a plant to meet its guarantees, after which his work usually ended.

Conservatism on the part of a designer in estimating the maximum capacity of tonnage handled by a belt, was a safe measure against contingencies, and led up to its readily meeting its guarantees. For instance, a belt might be employed to deliver, under stringent guarantees, say, 500 tons per hour at a certain speed. These guarantees, within certain limitations, might very well influence the designer in the adoption of a safe width of belt. But it was also quite possible the designer knew it to be capable of easily handling a larger amount. It was probable that the Author had been governed by such conservative estimates of capacity, and, if so, he was, in his opinion, justified in basing his conclusions thereon. Nevertheless, his view was that these figures were too low. He considered that the Author had taken the specific gravity of coal at too high a figure, while that for iron ore seemed low.

(Mr. F. T. Parker.)

If so, his capacity figures would be affected. However, to some extent, these specific gravities were dependent upon individual choice.

The Author might have improved and also curtailed the Table in the Appendix, by adding a column stating the constants he had used, and by taking the ratios of the specific gravities. He (the speaker) then went into detail to explain these points, and, upon suggestion, undertook to prepare an amended Table, relating only to the capacities given in the Author's Table. The Author had stated that the horse-powers were based upon his figures for maximum capacities. Assuming that plain bearing idlers were in use, his view was that these figures were low for the average, and high for the maximum capacities. This latter was in his favour. It was only reasonable to state that owing to the Author's long residence abroad, at times away from civilization, he was unable to tap sources of information available to those at home.

The Author was known by some members present, to be the engineer on the staff of one of the largest industrial concerns in the country. It was pleasing to pay tribute to the fact that the Paper had been read without previous comment or any alteration, and it showed a fine spirit on the part of his management. The Paper, coupled with the discussion, would be a valuable addition to the records of the Institution.

The PRESIDENT proposed that an expression of appreciation be conveyed to the Author, now on his way to China.

The Motion was carried with acclamation.

Discussion in Manchester, Thursday, 27th January 1921.

Mr. F. T. **Parker**, in introducing the Paper, said that the Author wished him to express his regret at not being there in person. At the Meeting in London he gathered he was expected to make a few introductory remarks. He was not then prepared, but was now. The Author's object was to place before them the results of personal experience on various plants for loading vessels with coal and minerals by means of belt-conveyors. An unloading plant was also described. Although the title of the Paper might be considered to cover a wider field, it could only have been intended to deal with one branch, and not that of other types of machinery in use for this or general cargo-handling purposes.

They were faced to-day by problems long neglected, partly due to a backward transport system, to environment, and largely due to the cost of raw materials and outgoings in the shape of much enhanced wages-bills. The situation affected industry in all its ramifications. The progress made, in this branch of engineering by British engineers, during the past decade or so, had been great, but it was not abreast of our industrial requirements, and not, so far as the number of modern installations were concerned, on all fours with developments elsewhere. Ironmasters here, and our Continental competitors, had been reaching out for some years to acquire properties abroad, where deep water conditions were handy, so that vessels could be loaded in open roads. There were instances of such plants at Bilbao, Cherchell, Bougie, Sebabna, etc. The installation of these plants presented no inherent difficulties, but the question of unloading vessels on arrival at our ports, was one calling for careful thought and judgment. It was in this country that more rapid developments would take place than heretofore. Brief mention was made in the Paper of a steamer built with its own unloading belt equipment. The Germans had made some progress in that direction, as the conditions on the Rhine demanded the quick loading of barges for river transport. These conditions did not obtain here, but it would be of interest to call attention to one or more points in passing.

(Mr. F. T. Parker.)

The first steamer built with a belt unloading outfit was constructed on the North-East coast to the joint designs of the late Mr. Christensen and Messrs. Doxford, and others had followed; the credit, therefore, belonged to this country and not, as generally thought, to Germany.

Prior to seeking these fresh sources of supply, ore was mostly brought from Spanish ports, and it led to the building of boats to deal specially with this traffic contingent upon our port facilities. It became apparent to ironmasters that this source of supply would ultimately cease to meet demands, and, in the early part of this century, iron ore was shipped from Southern Brazil, in direct competition with the Spanish fields. It was established that even such long route transport of iron ore, when carried in sufficient bulk, was practicable and remunerative. Attention was drawn in the Paper to the enormous iron-ore deposits in Brazil, to which the speaker could testify, and it was interesting to state that groups of British and American ironmasters were engaged in developing some of these fields. The Government of that country intended ultimately to link up two main route sections, and in the near future there would probably be a rapid development in the shipment of iron ore therefrom.

Having these remarks in mind, it became a matter for speculation as to whether ocean-going steamers for this work would ultimately carry their own belt unloading plants, in which case our dock arrangements might have to be altered to suit, or whether large grab-transporters, such as described in the Paper, would be more generally used. Attention was also directed to the progress in the perfection of automatic telpher-grab plants, which had been used on the Continent. British engineers had effected very considerable improvements in their design and general utility, and the speaker thought that this system would be a very keen rival to the grab-transporter by reason of its adaptability to local conditions, and to the economies it brought about by reason of its rapidity, flexibility, and labour saving. The greatest difficulty they had to face here was environment; it governed all other considerations.

The President had mentioned that Mr. Smith's Paper was the first for a number of years, and the speaker thought they were indebted to the Author for breaking the silence. The times compelled them all to pay heed to such contributions, irrespective of their individual opinions, and the Paper, with its discussion, would be instrumental in handing on to younger members some record of work well done.

The CHAIRMAN (Mr. William Fox) said the Paper developed primarily the mechanical handling of minerals in certain difficult situations abroad where little or no transport facilities obtained, and where economical transport and loading of vessels was entirely dependent on the installation of suitable plant at reasonable cost, which would ensure the development of mines and the loading and transport of their products to the consumer at competitive rates. The description of the special machinery designed and erected to meet the difficult conditions stated had proved of great interest. The equipment of the Port of Manchester included special machinery for the loading of coal for export, grain in bulk, etc.

The Port of Manchester, one of the best-equipped of ports, was, owing to its geographical position, situated within easy access of most of the important coal-fields in this country, and its railways being connected with all the large railway systems, it was therefore in direct communication with the mines. Very heavy coal and mineral traffic had been anticipated, consequently a special coal basin was constructed with railway sidings and equipped with six coal-tips, loading coal direct from the railway wagons to steamers. The standard coal-wagons at the time the tips were constructed were 10 and 12 tons, but in anticipation of the construction of larger wagons, coal-tips were designed to deal with wagons up to 30 tons. If wagons of the larger type referred to by the Author, say 80 tons capacity, were adopted in this country, there would be no difficulty in arranging suitable machinery for tipping in the same time as was now taken with standard wagons of 10 and 12 tons. It was quite impossible to compare the loading figures obtained

(Mr. William Fox.)

by the special coal-tips adopted where large-sized wagons were in use with the output in this country, where standard wagons were of 10 to 12 tons capacity. In view of the economical working of the coal-tips at Partington, the combined hoisting and tipping table was provided with three rams—main, auxiliary and balancing—the main and balancing rams being used for wagons up to 18 tons, and the three rams for wagons of larger sizes. The balancing ram was provided to prevent the tipping table lowering too rapidly, and provided pressure to the ram of the tipping table. The balancing ram accumulated pressure when the tip was lowering and the water contained in the cylinder was forced back into the pressure main, as the weight of the moving parts of the tip was sufficient to overcome the resistance of the balancing ram into the accumulator, consequently effecting a saving. Pre-war more than one million tons of coal were shipped in twelve months in this manner.

The tips were designed to be capable of a complete tipping operation in one minute. For obvious reasons, this rate of working was not obtained in actual practice. They had, however, unloaded up to forty-five wagons in one hour. He would be a very bold man who disputed the efficiency of a conveyor-band having the advantage of a constant feed from a large storage hopper.

He thought that the scheme at the Sebabna mines was excellent, and agreed with the Author that it was a mistake to have installed a bucket-conveyor. His experience of bucket-conveyors proved they were capable of doing good work, but were expensive in maintenance costs. He was not surprised that Mr. Smith had to pay a second visit to reinforce the bridge at Sebabna, owing to the vibration caused by the bucket-conveyors, as this was a common experience. During the construction of the Manchester Ship Canal, bucket and mechanical transporters were largely used for the removal of spoil, and proved effective.

The Author's reference to transporters was very interesting, more especially with regard to the Han-Yeh-Ping Transporter. The consideration of a scheme for this purpose was made difficult by the abnormal rise and fall of the Yantzse River.

Under specially suitable conditions, the loading of minerals into vessels would certainly be more efficient with the use of belt-conveyors. In this country for the loading of vessels the installation of coal-hoists, and for the discharging of minerals from vessels by grabs, either operated from level luffing and slewing cranes, or transporters, according to the special conditions, were adopted. At the Port of Manchester the belt-conveyors were used exclusively for the carriage of grain. At No. 9 Dock, grain was loaded direct from vessels on to belt-conveyors in subways nearly half a mile in length and conveyed into the elevator. Several vessels lying in the dock could discharge on to these bands simultaneously. The grain was raised from the ship's hold by means of bucket-elevators and conveyed to temporary hoppers, thence to belt-conveyors.

At No. 1 grain elevator the intake-belt, which was 36 inches wide, running at 600 feet per minute, conveyed 470 tons of grain per hour. The grain was loaded direct from the ship by means of a belt bucket-elevator supplemented by a pneumatic plant. The export belt-conveyor delivered bulk grain into barges and coasters at the rate of 410 tons per hour.

He agreed with the Author that idlers were destructive to belts. It was quite possible so to train a belt that idlers rarely came into use. The belt-conveyors at the Port of Manchester had no more than three idlers on each side, and those were on the return, even with conveyors over 500 feet in length.

With reference to the use of grabs for unloading ore, the Port of Manchester had a number of electrically driven portal cranes of 5 tons working load really designed for a greater load. It was very necessary to have such a margin owing to the varying weight of ores. Grabs were operated by wire-ropes ; the weight of the grab was 2½ tons fitted with teeth and lifted at least its own weight at an operation. The vessels from which the ore was unloaded generally had ordinary hatchways, and several cranes worked from one hold in accordance with the size of the hatchway. From experience, he believed this was the cheapest method at present known of discharging ore from a steamer.

The Author referred to the Han-Yeh-Ping transporter grab weighing 7 tons empty and 11 tons full. It appeared to be unduly

(Mr. William Fox.)

heavy in proportion to the weight of material lifted. In this country where steamers received bunker coal when lying at anchor, special floating loaders, either a combination of belt-conveyors and elevators, or transporters and grabs were used, the former being used principally for side port loading and the latter for over-all loading.

Mr. J. PHILLIPS BEDSON said that what interested him particularly was the use of wire-cables. He had seen many installations where wire was used for transporter purposes. Those who had been in Belgium would have seen the extent to which that country had availed itself of the advantages of aerial transit in the removal of spoil from the collieries and forming, not an ugly pit bank, such as existed in England, but something like a beautiful cone in the middle of the country.

It would have been of great interest to hear something of the American experience. Of course, the loading of ships was to a very great extent an easier job than the unloading. On the great Lakes in America, where large ore boats were used to bring the ore from the iron districts to go to the Pittsburg and Cleveland districts, both problems had been taken up in the most efficient manner. Wire had been used for transporting in very elaborate forms and in a very primitive manner. On the fiords of Norway a large quantity of hay was produced on the high lands, and it was a common practice there to run loads of hay on a single wire from the top down to the lower level. That method was also used for other things. He remembered when the East River Bridge was being built from New York to Brooklyn, there was a small rope which carried the first man that passed over from one side to the other. The members might also have noticed, in the large quarries or open mines that were in operation in South Africa, the network of wire-ropes running from the top right out into the valley, on which the ore was carried. It was a splendid example of aerial transit and the transporting of the material was exceedingly cheap.

Mr. CECIL BENTHAM said that on page 69 one paragraph was devoted entirely to the comparison between machinery and coolies, and in the next paragraph the Author stated that he proposed to deal with plants which had proved that the loading and unloading of steamers could be done at less cost than was possible previously by using native labour. He thought it was putting it on a rather low plane to regard it only as a question of cost. But to his mind a more important factor was the question of time and the more rapid execution of the work—either loading or unloading. During the War they had had a typical instance of that. In discharging ships in France the material was brought out of the ship at a rate which was quite impossible with manual labour; even if one had all the men in the world to draw upon, the work could not have been done at the rate that the machinery did it, because there was a limit to the number of men one could apply in a particular area. He thought that was the governing factor of most of these appliances.

The Author attributed the success of the United States and Germany in the production of iron and steel to the attention paid to the handling of materials in bulk. He thought that suggestion was quite wrong; success was due to economic conditions. Engineers had kept pace with the requirements of this country. They did not load ore into ships as described in the Paper because they did not need to do it. It was necessary to load coal because a fairly large amount of coal was exported, and he had seen nothing in the Paper which indicated that the coal loading appliances in this country were second to any in the world. One type which was mentioned—the staiths—was not always easy to apply, but it gave the best results where it was applied. The difficult problem was unloading. In loading one could use gravity to a great extent, whereas in discharging one had to pick the stuff up, which was sometimes very difficult.

With regard to coal and ore, with which the Paper particularly dealt, there had been nothing so far for unloading to beat the grab. He limited that remark to ore and to coal in big lumps. But he noticed that the Author dealt with one kind of grab only—that which was slung on a chain or rope. It hung on a flexible rope, and it went into the hold and swung about in the hold. That was

(Mr. Cecil Bentham.)

the most common form; but in America, where there was a large amount of ore transported on the Lakes, far larger than the quantities dealt with in China or any other part of the world, 50 per cent of the ore that came out of vessels was discharged by a grab of another form. This grab, known as the Hulett grab, was worked with rigid members, not flexible members as described in the Paper. He assumed that the Author had kept to his own experience, but in dealing with the subject this other type ought to have been mentioned, because it dealt with far larger amounts than the flexible grab. It was carried on two arms which went down parallel, and it was worked by rigid levers, the individual capacity being from 10 to 15 tons per grab. The grab described in the Paper was a very heavy one. In dealing with iron-ore, a heavy grab was undoubtedly necessary; one must have enough weight to force the grab down into the material without it tumbling over, as there was a tendency to do. When they started discharging iron-ore with grabs they could not get the grabs full. That difficulty was overcome by putting more weight into the grab itself, until they got a 7-ton grab lifting 4 tons of ore. One could design a grab of about 4 tons strong enough in other respects to lift that ore, but it would not go into the ore.

With coal the problem was not quite the same. The coal was lighter and the grab sank into it more easily. In those plants which dealt with both classes of material, he would have felt inclined to use two grabs, one for ore and one for coal. It was no use swinging 7 tons of grab about for 4 tons of coal, and it seemed to him that was what was happening in these plants. He thought that the English practice might well be applied to China in this case.

He agreed with what the Author said about taking very little notice of freak records. Last week he came across a record which he had not seen before, of a ship on the Great Lakes which had been loaded with 10,000 tons of ore in twenty-five minutes, and it was also stated that the ship was on the slip one hour. The principle of the coal staith was applied to iron-ore, and instead of just feeding the ship at one point, it was fed at a large number of points by shoots from bunkers, so that the ship sank down steadily as the ore flowed in.

The Lake boats were very different from ocean-going boats; there was only one big hold which could easily be filled.

The Author had only dealt with two of the materials which were loaded in bulk, but the one which was most widely carried in ships was grain. This country depended for food upon the transport of grain, so that from their point of view it was even more important than the transport of minerals. He noticed that the Author confined himself strictly to certain plant, and he gathered that all the belt-conveyors mentioned were trough-conveyors. In his own business they used many flat conveyors—that is to say, the belt ran flat, in addition to the trough type. The trough-belt had its advantages, and was quite right for dealing with ore, but when dealing with grain the advantages were not so pronounced. Both types were used, the choice depending upon the conditions. The amount of work that could be got out of the flat belt at very low cost was really astonishing. The trough-belt was not quite so perfect because it was distorted in running, but with the flat belt there was practically no distortion, and it would run many years unless a mistake was made somewhere in the supports. The trough-belt gave much greater capacity for a certain width, and in the Ship Canal elevator, to which the Chairman had referred, there were trough-belts in the subway, but at other parts of the elevator there were flat belts. The capacity was the same. The trough-belt, 24 inches wide, and the flat belt, 30 inches wide, carried 200 tons per hour at 750 feet a minute. Information about most matters connected with belt-conveyors was given in a Paper by Mr. James Tinto, read before the Manchester Association of Engineers in 1916. Belts manufactured by Mr. Tinto's firm according to the specification given in that Paper were very reliable; they supplied all the conveyor-belts—about three miles in length—to the Ship Canal No. 2 elevator.

The CHAIRMAN mentioned that the belts were made to the Ship Canal Co.'s specification.

Mr. BENTHAM said he would give the Ship Canal Co. full

(Mr. Cecil Bentham.)

credit for that. Those belts had been running five or six years and none of them had been changed. Most of them would run ten years if the construction was all right. The question of belts was largely governed by price.

The CHAIRMAN said that the Ship Canal Co. had some flat belts which had been working twelve years on the top floor of No. 1 elevator.

Mr. BENTHAM said there was no doubt that a flat belt would run a very long time, providing one got the right belt to start with. There was one point in the comparison between grain belts and those conveying minerals. The former did not wear to quite the same extent or get the cuts that the ore belt was likely to get, and the rubber facing was much thinner. A cover $\frac{1}{32}$ inch was considered fairly thick for a grain belt, whereas the Paper referred to belts with $\frac{3}{16}$ inch of rubber on the working face. Some belts had even more than that, and some had thicker rubber in the middle than at the side.

The speed of the belt was another aspect of the subject which the Author had not covered fully. He mentioned a speed of 500 feet a minute, which was quite a common speed. In this country 800 feet per minute was run on grain, and, in America where they had larger quantities to deal with, they ran with bigger belts at 1,000 feet per minute on grain. Smaller belts were not run at so high a speed. He thought that was rather opposed to what the Author suggested. Rubber belts 3 feet wide were run up to 1,000 feet a minute in America, but with 24-inch belts the speed had to be kept down or the grain would scatter off the belt. Many engineers in the country had a feeling that they must have very large pulleys for driving belts. The driving pulleys of the Ship Canal Co.'s belts were mostly 16 inches in diameter, and they had done excellent service the whole of the time, in spite of prophecies of absolute failure. His experience generally was that the belt tended to run up the curving rolls on the side where the load was placed, and he could only account for that by the same theory as applied to a crowned pulley, the belt bent slightly round the troughing roll and ran up that side. The design of the carrying rollers was very important. They must be balanced if run at high speed. He himself was accustomed to higher speeds than the Author ; he had run at from 50 feet to 1,000 feet, whereas 500 feet was about the Author's maximum, so probably he attached more importance to details of that kind than Mr. Smith did when he wrote the Paper.

The Author got to the heart of the conveyor problem when he spoke of the feeding hoppers. He was in America last year and went to see some installations of grain elevators. He inquired whether they had any difficulties with them, and particularly asked about the feed-hopper. He was told that no difficulty was experienced with them, but when he went to see the feed-hoppers he found scarcely a single instance where the feed-hopper had not been altered, which showed that there had been severe trouble with them. Some of them had been altered once and then altered back again. He quite agreed with the Author with regard to having smooth plates. It was a point that was sadly neglected, but it made all the difference when one was moving grain, which was almost like a stream of water.

Mr. W. G. Smith said the Author remarked (page 68) that a principal reason why in the production of iron and steel this country had been surpassed by the United States and Germany, was the attention they had paid to the handling of materials in bulk by special machinery. There were, however, many other factors to be taken into consideration. In his opinion the primary reasons were greater ore deposits, the easy working of minerals which were more accessible, and the consequent cheaper cost, all tending to an increasing production. Long distance transport of minerals in the United States from the mines to the reducing centres, was of course, a disadvantage. On the railways it had necessitated the adoption of larger wagons—75 tons capacity—and on the lakes and rivers, special carriers. The loading and discharging of the ores required specially designed machinery. He believed that the machinery described in the Paper had been obtained from this country, which was sufficient tribute to our up-to-date knowledge.

(Mr. W. G. Smith.)

He thought that all were in agreement with the Author that a belt-conveyor would have been much better at Sebabna than a bucket-conveyor, and more economical, both in working and maintenance costs. It was difficult to understand the owner's lack of faith in a belt-conveyor, as such belts had been in use all over the world for carrying ore, and were proved and established before the Sebabna plant was erected. He was in agreement with the Author's remarks on conveyor-belts and their construction. The specification given was a good one, and very similar to that adopted at the Port of Manchester.

The Author estimated that under equal conditions a hydraulic hoist would dump 4½ tons, an electrical hoist 5½ tons, and a belt-conveyor would carry 7½ tons per b.h.p. This, he thought, was open to doubt. The Author had shown special preference to electrically-operated belt-conveyors and coal tips as against hydraulic coal-tips. This was entering on very controversial ground, as experience proved that the adoption of the several classes of machinery depended upon the special conditions which obtained; under these circumstances hydraulic coal-tips had proved equally efficient. At the present time there appeared to be no reason for their displacement. The Author attached too much importance to the displacement of the double coal-tip at Hull by belt-conveyors. The coal-tips were erected at the end of a pier or jetty, and owing to the difficulty in working the wagons to and from the tips, due to the restricted area of the jetty, belts conveying coal from the shore were adopted. The Port of Manchester, with its properly laid out coal-basin, had proved and established the efficiency of coal-tips worked hydraulically.

With regard to the Durban conveyor, it would have been interesting if the Author had stated why a coal-tip would not have met the requirements more efficiently, seeing that a dumper had to be installed as part of the scheme. The only apparent advantage was that a vessel could be coaled without being moved in the berth, such movement being effected readily and economically by the ship's winches. The figures given by the Author with regard to this conveyor would not permit of definite examination without amplification. The plant had an aggregate provision of 700 b.h.p. in several motors. The actual current consumed on the average under maximum working conditions was 150 kw., equal to about 200 e.h.p. The total h.p. apparently was much in excess of the actual requirements, but no doubt this was partly explained by the intermittent load of the dumper characteristic of this class of machine. The two hoisting drums of the dumper were driven by two continuous motors, each of 150 b.h.p., interconnected through gearing to act as one unit, giving a maximum rope speed of 100 feet. It was evident that this h.p. would be inadequate; consequently it could only be assumed that the load was lifted through multiple purchases, at a consequent reduced speed. The Author's comparisons of the speed of loading obtained in this country as compared with other countries (page 94) were in the nature of a reflection, but when it was considered that the railway wagons of this country were standard 10 and 12 tons, it would be readily conceived; and if the large wagons referred to by the Author were adopted here, coal-tips giving an hourly output equal to the figures stated by the Author would be easily obtained. The special trucks in use in America were used solely for conveying ore from mines to reducing centres, whereas in this country the railway wagons were used for general purposes.

Mr. J. W. GOMERSALL said the Paper followed a remarkable Paper read by Mr. Thomas Robins in 1896 before the American Institute of Mining Engineers, and a further Paper contributed by Messrs. Robertson and Johnston to the South African Institution of Engineers in 1916, dealing very adequately with conveyors in general, which were an important element in the South African goldfields. In that Paper details were given which had been omitted by the Author, but touched upon by Mr. Bentham, namely, belting plies, the driving of the belts and their form. The ordinary trough-belt had been too deeply troughed. Modern practice had been to decrease the troughing and to widen the belt, letting the speed take care of itself for the time being.

He noticed in the illustrations that the coal and ore conveyor-belts were covered or roofed in by galvanized plates to keep out the

(Mr. J. W. Gomersall.)

moisture, because where there was moisture excessive wear on the belts occurred. In a Paper on Wire Ropes read by Mr. A. S. Biggart * when the Forth Bridge was being erected, it was stipulated that the pulleys should be at least thirty times the diameter of the rope. Something like that should be done on broader lines with a belt. Rubber obeyed all the laws in regard to elasticity, but it could not be expected to go round a sharp corner.

Mr. C. P. KININMONTH said he would like to ask a question about the Durban loading plant, Fig. 16, Plate 6. The fixed conveyor was brought a considerable distance back from the edge of the wharf and communication was made to the ship by means of a travelling-cross belt. He would like to know why the belt bridge was not put at the edge of the wharf, thus dispensing with the travelling conveyor. One would suppose that the wharf was intended for other traffic besides the loading of coal and similar material, but that point was not made clear in the Paper.

With regard to the unloading of ships, which was dealt with in the description of the plant at Han-Yeh-Ping, he was particularly interested as to the future developments of ship discharging. The Author was non-committal on that point, but Mr. Parker went rather more fully into the possibility of ocean going ships being ultimately constructed fitted with appliances for discharging themselves by means of belts and elevators. If the conditions permitted, he did not suppose English engineers and shipbuilders would hesitate very long before they had designed a perfectly satisfactory ship to do that, but it must be borne in mind that there were serious obstacles in the way. The shipowners themselves were perhaps the chief obstacle, because they did not care to invest much capital in a ship which might only be used for one kind of traffic. There was also the great difficulty with the watertight compartments, which in an ocean-going ship would necessitate constructing the ship so that every hold was a separate self-

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* Proceedings, Inst.C.E., 1890, vol. ci, page 231.

discharging entity. On the Great Lakes there was a much better opportunity because the ship had one hold, however large it might be.

In this speculation on the possible developments in ship unloading of bulky materials, the Author appeared to favour grabs. Mr. Bentham had pointed out that the grab had to be 7 tons in weight to lift 4 tons of ore. After elevation, to complete the horizontal travel, 50 tons of machinery had to be moved along the transporter. He could not help feeling that the future of discharging did not lie with the grab but lay rather with continuous systems, such as the bucket-elevator and the pneumatic plant. His firm recently designed a bucket-elevator for handling and discharging iron-ore, which could be made to reach any part of the hold of an ocean-going vessel. The elevator—which was carried by a balanced arm in the ordinary way—was capable of being revolved by power about its own vertical axis, and the lower portion of it was capable of being canted up at an angle, hydraulically or otherwise. By a combination of those movements, the whole of the bottom of the hold could be covered.

Another problem his firm were asked to solve was the discharging of run-of-mine coal as received at South Country ports. All the small coal could be handled quite well by the pneumatic system ; the big lumps naturally could not be dealt with. They designed a machine which would carry a very large pipe capable of permitting the passage of perhaps 7-inch or 8-inch lumps and at the same time carrying a nozzle. This machine was provided with a coal-breaker and an appliance to pick out the big lumps and put them into the coal-breaker. First of all the pipe got to the bottom of the ship. Then the structure carrying the nozzle would run up and down the bottom of the bank of coal that was formed when the pipe had reached the bottom, sucking away all the small stuff, pitching the lumps into this breaker, and passing it from the breaker into the pipe again.

The CHAIRMAN asked as to the size of the lumps which would be taken by the suction system.

Mr. Kininmonth replied that it gathered all small coal up to 6-inch or 7-inch lumps, and that a quarter of a cubic foot could be handled, provided there was a large proportion of small material.

Mr. F. T. Parker said the discussion had developed along the lines expected, as the title of the Paper allowed more latitude than the Author anticipated. Nevertheless, it showed more than a passing interest in the subject.

In addition to the Papers referred to by Mr. Gomersall (page 141) he would also refer him to another read by Messrs. Mooney and Darnell * before one of the American Mining Institutes. It was written by men connected with a large belt-making concern, but, like others, was open to criticism and reservations. Some engineers here held the view that our conveyor-belts were not up to the best American standard, and he concurred in this. Climatic conditions appeared to favour American manufacturers. But the onerous conditions under which belts had sometimes to work were now better appreciated by our makers, and there had been a decided improvement in the build and manufacture of these belts of late years. They had, however, to be better still to compete with those mentioned.

The records of belt performances published in the American Press were apt to prove misleading, as upon closer examination they were no better than those obtained elsewhere. He had noticed a tendency carefully to omit information to permit of fair comparisons. Rapid progress had been made in this country, as not only had British firms more than held their own in competition from all sources, but they had also shown the way in dealing with some of the problems as they had arisen.

Comparisons were sometimes also apt to be misleading, and he felt it important enough to reiterate the importance of taking into consideration the question of environment. It played a very large part in the solution of handling problems, especially here, and was not sufficiently appreciated by those without expert knowledge of the subject.

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* American Inst. of Mining Engineers, Sept. 1915.

The figures in the Appendix were derived from empirical formulæ computed by the Author, and were based upon a large amount of data he claimed to have collected in the actual running of plants under everyday working conditions. The speaker had stated elsewhere that he was not in agreement with the Author, but it did not alter the fact that these figures were given without bias, and for that reason alone, apart from any other consideration, they deserved to be closely examined. The Author had attempted to deal with this question in a rational manner, although his results were only empirical. This rational treatment might well be developed, not by taking factors to cover smalls, mixed, or lump material only, but by the introduction of the actual size of the material to be conveyed as an average, a suitable coefficient of solidity, and a factor to allow for normal average conditions of feed and labour, so far as this latter was humanly possible. It was to be hoped that an attempt would be made along these lines, as it would be of service to those contemplating the installation of this class of plant, and guide them in checking statements made by interested parties.

Mr. Gomersall had doubtless heard of a clause wherein it usually stated that a belt running at a certain speed would deliver "at the rate of" so many tons per hour. Other clauses were usually introduced into belt contracts. The speaker admitted these clauses were fair ones from the suppliers' point.

One or two actual results might prove of interest. Three steamers were loaded on three consecutive days by one of the plants shown on the screen that evening. Loading began in the morning and finished the same evening, a desideratum with open road loading. The steamers were of 3,100, 4,300, and 4,900 tonnage respectively. The average rate of loading in the same sequence was, 430, 572, and 450 tons per hour, consequently, as the plant was installed for a duty of 400 tons per hour, the results were 30, 172, and 50 tons in excess of the quantity required. A marked difference would be noted between the first and third, as compared with the second result. This was due to stoppages for changing over hatches. During this time the weather was fine, but it was necessary to mention that as the storage was an open one, rains had a bad effect, with the

(Mr. F. T. Parker.)

result that the plant had been known to deliver at an average rate below the 400 tons per hour.

He had noticed that several members, both present and in London, had drawn attention to the weights of the moving load and grab of the unloading transporter plant at Han-Yeh-Ping. The speaker would endeavour to clear this up. He thanked them on behalf of the Author for their kind reception.

The CHAIRMAN said they must be careful not to be carried away by what was said about the grab being forced down into the ore. When dealing with some ore, if the grab were forced down, it might go through the ship's bottom. With reference to the Lake boats, of which Mr. Kininmonth spoke as having a big hatch going the whole length of the ship, there was no Board of Trade mark for those boats. It would be different if they were in England.

Votes of Thanks to the Author, to Mr. PARKER for presenting the Paper, and to the Chairman for presiding, were carried.

Communications.

Mr. W. H. ATHERTON wrote that it would be interesting to learn the names of the firms which made the fine plants described in the Paper. The plates were of exceptional magnitude and quite out of the ordinary run of everyday engineering practice; but the tendency for some years had been in the direction of still larger plants. The circumstances in which it was necessary to handle any material at the rate of 2,000 tons per hour (page 82), would surely be very rare indeed. One wondered how the ore was to be fed to the conveyor and removed from the neighbourhood of the delivery point at that prodigious rate of working. He thought that it would be better to install duplicate conveyors in parallel than to rely entirely on a single very large conveyor, thus risking a total hold-up.

In the year 1897 the Author's firm made a shallow-troughed belt-conveyor of 333-feet centres, 30 inches wide, for the Sheffield Gasworks, having a capacity of 80 tons of coal per hour at a speed of 200 feet per minute, and this was then thought to be a large conveyor. Even to-day in British gasworks and power stations there was practically no demand for conveyors exceeding 80 tons per hour capacity. No colliery and no gasworks known to the writer in this country had ever called for a larger moving capacity in a single conveyor than 600 tons of coal per hour, which was quite an exceptional figure.

The preference of the Author for conveyors of the belt type was no doubt quite justified in the case of conveyors of such exceptional capacity as he had mentioned. Up to a capacity of about 100 tons per hour, however, a good case could be made out for chain-belt conveyors running at a slow speed, standard chains, wheels and buckets being available. Indeed, the writer's firm had successfully constructed inclined continuous bucket chain elevators of the total vertical lift of 150 feet and with a capacity of 250 tons of crushed rock per hour. The Ley bushed chains for these elevators were 12 inches pitch, and had already worked eleven years without being renewed, the pins and bushes being of hardened steel.

The bucket-conveyor at the Sebabna Mines for shipping iron-ore was a very interesting plant of exceptional capacity. It was stated in the Paper that the length was 594 feet between centres, and that the capacity of the bucket was half a ton; but the length of the buckets was not stated. It would be instructive to know what was the chain speed, the pitch of the chain, and the total capacity of the conveyor in tons of iron-ore per hour. The auxiliary conveyor appeared to be about 42-feet centres, and afforded a means of giving a variable point of delivery. One alternative would have

(Mr. W. H Athreton.)

been to use a tipping-bucket conveyor, and another a tipping-tray conveyor. If a belt-conveyor had been adopted, the alternative to the auxiliary conveyor would have been either a travelling throw-off carriage or a series of fixed dumpers.

It was stated (page 87), that all inclined conveyors should be driven through worm-gearing to overcome any tendency of the belt to run back when stopped in an overloaded condition. This was open to question, because ordinary worm-gears were less efficient for transmitting power than spur-gears, and were therefore wasteful of power. Moreover, if a multiple threaded worm of high mechanical efficiency were used, this would not be effective in preventing running back. What was the objection to using a ratchet-wheel and pawl, or a friction-pawl and wheel? Either of these would permit of a train of reducing gear of high efficiency, and yet prevent running back.

Referring to the Durban belt-conveyor (page 91), it was stated that a 48-inch belt had a maximum capacity of 800 tons of coal per hour. This seemed a very high capacity for a 48-inch belt, and the writer would prefer a wider belt with shallower troughing and run at a slower speed. To get maximum durability out of a conveyor-belt, it should be run flat and not troughed; also to get maximum carrying capacity out of a belt of given width, it should be deeply troughed, and in this way the first cost could be reduced greatly. To get a reasonable compromise, the belt should be run with shallow troughing only. The radius of the trough might be made equal to the width of the belt, rather than the width divided by 1·3. In like manner, to get the maximum capacity out of a belt, one had to run it at a high speed, but to get maximum durability it should be run at a rather slow speed. The compromise in this case was to install variable-speed motors and run the belt at as slow a speed as the hourly requirements permitted, the highest speed being kept in reserve to meet the peak load. Thus the dual requirements of relatively low first cost and high durability were, as far as feasible, both satisfied.

As regards the relative capacity of belt-conveyors of large width, it was noteworthy that the tonnage capacity did not vary simply in proportion to the width, but as the *square* of the width. Thus, if a 20-inch belt were compared with a 40-inch belt, both fully loaded, the latter would carry four times as much coal as the former at the same speed. On the other hand, the capacity was directly proportional to the speed ; so that a belt running at 400 feet per minute would carry twice as much coal as a belt running 200 feet per minute, assuming, of course, that the belt was kept uniformly loaded, instead of there being wide gaps of bare belt with patches of coal here and there. The speed must not be so excessively high that the fine coal would be blown off the belt by contact with the air.

Mr. J. M. HENDERSON wrote that a plant for transporting and loading iron-ore into vessels similar to that at the Sebabna Mines was erected at Sadouna, in Algeria, about fourteen years ago. The aerial ropeway at Sadouna was four and a quarter miles long, and could handle 20 tons per hour in individual loads of 5 cwt. This line was on the single-rope system and was also worked in conjunction with a cantilever-conveyor arranged similarly to the conveyor described by the Author. In view of the trouble experienced with the bucket-conveyor in surging, the writer thought the Author was right in stating that the belt-conveyor was more suitable for installations of this kind. The capacity of the conveyor at Sadouna was sufficient to enable boats of 1,500-tons capacity to be loaded in one day.

As an example of aerial ropeways loading ships without the use of a mechanical conveyor, the aerial ropeway at Craster, Northumberland, might be cited. This ropeway conveyed crushed stone and road metal from a breaking plant to the top of large bunkers erected on the pierhead of the harbour. The road metal was transferred directly from the bunkers to the vessel, being loaded by means of inclined shoots. The capacity of the ropeway was about 40 tons per hour, the individual loads being about 6 cwt.

There was an installation of the double-inclined or "Jig-Back" gravitation ropeway at Duke's Grain Warehouses, Liverpool, Fig. 34, Plate 10. The span was 150 feet, capacity about 30 tons per hour

(Mr. J. M. Henderson.)

in individual loads of 10 cwt. net. The ropeway was used for transferring grain from the upper floor of a warehouse to storage bunkers placed on the quay side. From the latter it was transferred to the vessel through a shoot. An aerial cableway, as installed for loading and unloading vessels at the docks, Rio de Janeiro, was shown in Fig. 35, Plate 10.

Overhead runways were extensively used for loading and unloading vessels. An example of an installation of this description was to be found at a wharf on the River Po, Italy. This runway, which was provided with a branch extension arranged to serve a coal store, had a length of 265 feet, and was capable of dealing with a load of 2 tons. A hoisting and travelling carriage, travelling at at speed of 300 feet per minute and hoisting the full load at 40 feet per minute, was provided.

In referring to grab-transporters, the Author mentioned the possibility of running a number of hoisting and travelling carriages round an endless track. This was a common arrangement with a fixed structure and could, undoubtedly, be applied to a moving structure for loading vessels in certain cases. Transporters described by the Author appeared to have been designed exclusively for handling bulk material, and possibly where such large quantities of materials had to be dealt with, the very great weight of the structures and of the moving load, compared with the useful load, was a matter of less importance. The fact might be noted that in the case of the Han-Yeh-Ping transporter, in which the total weight of the machine was 680 tons, the load, which had to be moved backwards and forwards each time the grabs were filled, was 100 tons, and the useful load of materials was apparently 20 tons only. Where material was handled by grabs, the useful load was usually small in comparison with the moving load, but where grabs were not employed, the proportion could be much greater.

Aerial ropeways worked in conjunction with conveyors were suitable for loading ships with bulk material in large quantities, but were not usually applicable to handling miscellaneous cargo, for which purpose machinery with a hoisting unit was necessary. Also, in such cases, the quantities dealt with were usually smaller and, if mechanical means were to be employed, a less expensive installation was required. The conditions were, in such cases, most often met by cranes of various descriptions but, to satisfy certain conditions, aerial cableways had been employed. These might be arranged either so that one support extended from the quay and overhung the ship, or with the outer support erected on a foundation in the sea so that the ship could be moored between this support and the quay. Many installations of both those types had been erected in various parts of the world.

Mr. F. G. MITCHELL wrote, in continuation of his remarks at the Meeting (page 123) that, during the discussion upon the Paper, attention had been drawn to the statement that the travelling machinery in connexion with the Han-Yeh-Ping ore unloading transporters weighed 100 tons, while the amount of ore lifted at each operation only amounted to between 4 and 5 tons. It would be noted that the Author definitely stated that the two grabs and attendant machinery weighed nearly 100 tons. Actually, the weight of each travelling carriage, with its empty grab complete, was under 40 tons—which included every item of mechanism necessary for unloading the ore and discharging into the receiving bunkers. The proportion between the weight of the machinery and the ore handled was not excessive when it was remembered that the carriage was able to revolve as well as travel along the track, that the weight included, in addition to the machinery, the roller path for the revolving motion, all structural work of the carriage, and the motors, resistances, controllers, etc., for the complete mechanical and electrical equipment.

The reason the slewing motion was added to the travelling carriage was to give the grab a wider range of operations in the direction fore and aft of the boats, without the necessity of moving the boats or the transporter. It was found that, for this particular installation, it was a decided economical advantage to carry the extra weight necessary for the provision of the revolving machinery, rather than to expend time and power in moving the boats or the transporter, and although the travelling load did equal about

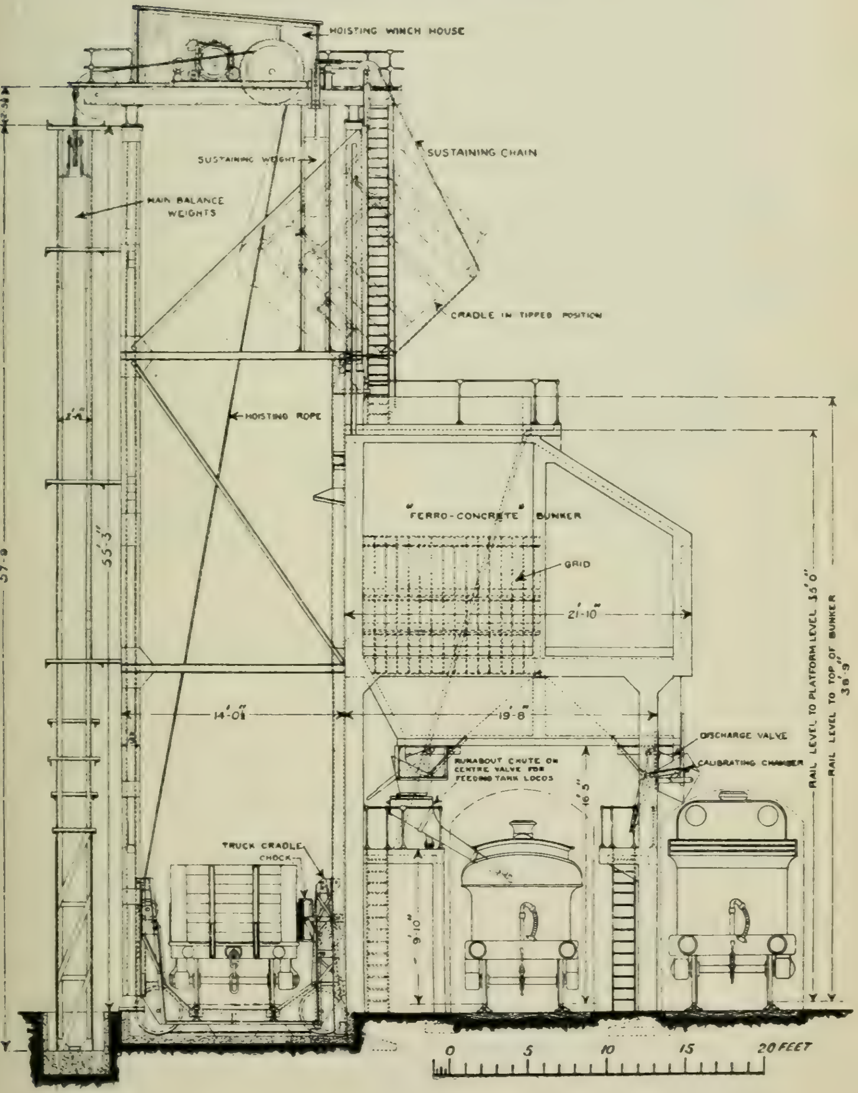
(Mr. F. G. Mitchell.)

40 tons, compared with 4 to 5 tons of ore loaded per journey, the power required for travelling this load at the comparatively high speeds necessary was only 30 h.p. Considering that this power was only applied for short periods during each operation, the actual consumption of power for travelling the load represented a very small item, and in practice approximately 5 B.T.U., which it would be noted was a very low figure for the conveyance of the ore from the boat to the bunkers, and probably less than any other possible method.

Mention was made in the Paper, and by various members during the discussion, of high-capacity tipplers for rapidly discharging wagons. It was interesting to note that the earliest of the large tipplers mentioned during the discussion was actually manufactured in this country, and had been tipping wagons up to 40 tons capacity successfully for twenty years at the maximum rate of about twenty-five per hour. Tipplers of such a high capacity were not possible in this country, as trucks over the standard 12-ton size were not in general use, but tipplers were being erected in this country for this size of wagon of the same general design as those described in the Paper, and an illustration of one of these was shown, Fig. 36, which was now nearing completion for the L. and N. W. Railway Co., for the purpose of loading locomotive engines. The Great Eastern Railway Co. were installing a truck-tippler for 20-ton wagons arranged to tip one wagon per minute—illustrating that this country was in no way behind Continental or American competitors with this class of machinery.

Both for unloading and loading ships with general and mixed cargoes, the automatic telpher plant would undoubtedly be very greatly used in the near future, as by the latest devices it was possible to unload a steamer and deliver the load quite automatically into that portion of the store or quay where it had been arranged to receive it. Such a plant would consist of a travelling tower running along the quay front, with a hinged arm which could plumb any steamer-hold. A fixed connecting track would be arranged parallel with the track of this travelling tower, and connected with tracks leading to the various stores and sidings that had to be

FIG. 36.—*General Arrangement of Truck Tippler* (Mitchell) *for Standard Railway Wagons.*



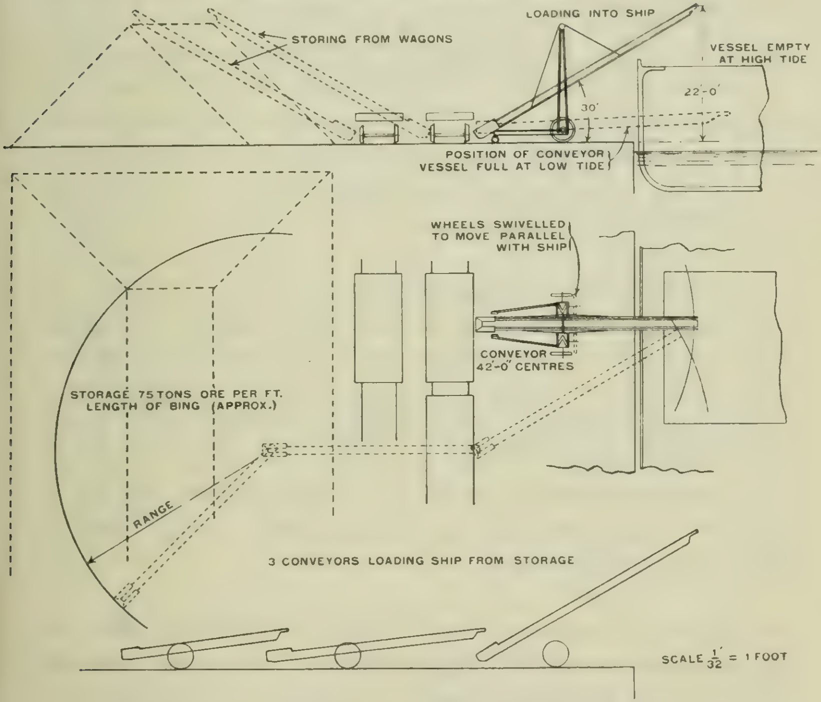
(Mr. F. G. Mitchell.)

fed from the quay. On this track several telpher-cars would be arranged running always in one direction, and when empty stopping on the tower ready to receive the load. A driver was stationed on the unloading tower, and he had control of the particular telpher carriage that was then on the overhanging boom. He lowered the hook to which the load was to be attached. When the load was hoisted, he dispatched that telpher to the particular store for which the load was intended, and the next telpher-car immediately and automatically took its place on the boom ready for loading by the same driver. When the telpher-car reached its destination, it stopped automatically and was unloaded by the attendant in the store, and when unloaded returned again automatically to the tower to be loaded again. Any number of telphers could be run on such a system, and by this arrangement all labour for loading, unloading, shunting, etc., was done away with, and the goods delivered exactly where required without attention. Automatic telphers, similar to those required for such a plant, were now in course of manufacture, and when in operation would undoubtedly represent a considerable advance in the "Mechanical Loading of Ships."

Mr. WILLIAM H. PATCHELL (Member of Council) wrote that the Paper as printed was very interesting and would be useful. As one who had been privileged to see and report on the Paper as first received, he thought it was only due to the Author to say that exigencies of space and cost of printing had caused what was, in the writer's opinion, a regrettable diminution in the value of the Paper. The original draft contained many points of great interest and helpfulness to anyone who had to handle and erect machinery in the field. These and other interesting details had been lost in the process of "editing."

Mr. T. M. RITCHIE wrote that while fixed and semi-fixed conveyors were largely used, the adaptation of a portable machine was comparatively new. The advantages of the portable equipment were obvious, in view of the varying size of the vessels, and position of the hatches, while the loading operation might be carried on without relation to fixed plant. The comparatively low first cost and running charges also recommended this form of transportation plant. Fig. 37 showed a scheme of handling manganese ore at a Russian port, from wagons to ship, and the means adopted for storing and reclaiming material at the quay side. The plant consisted of four conveyors, each fitted with elevating mast and swivelling axle, and the value of these features and flexibility of the arrangement could be better followed from the drawing than by description. Of special interest was the elevating mast, which regulated the point of discharge to accommodate the trim of the ship and state of the tide.

FIG. 37.—*Scheme for Loading Manganese Ore by Four Portable Conveyors: capacity of each,* 80 *tons per hour.*


LOADING INTO SHIP
STORING FROM WAGONS
VESSEL EMPTY AT HIGH TIDE
22'-0"
30'
POSITION OF CONVEYOR VESSEL FULL AT LOW TIDE
WHEELS SWIVELLED TO MOVE PARALLEL WITH SHIP
CONVEYOR 42'-0" CENTRES
STORAGE 75 TONS ORE PER FT. LENGTH OF BING (APPROX.)
RANGE
3 CONVEYORS LOADING SHIP FROM STORAGE
SCALE 1'/32 = 1 FOOT

Elevation showing Conveyors used in series.

(Mr. T. M. Ritchie.)

The material was shovelled from the wagons to the hopper of the conveyor, the belt being 18 inches wide and having a capacity of 80 tons per hour. The total weight of the conveyor, as shown, was approximately 2 tons.

A necessary feature in the design of this type of conveyor was to obtain maximum strength and light yet robust construction to withstand the arduous service demanded. In the great majority of conveyors this point had been entirely overlooked, with the result that the conveyor, due to the weight, ceased to be really portable. Although the starting torque was very high, the power required to drive conveyors was frequently overestimated. On a recent test the following figures were obtained :—30-foot portable machine, at an angle of 30°, conveying 25 tons of rock phosphate per hour, starting torque machine empty, 2·88 kw. ; running full load, 0·38 kw.

With regard to the problem of unloading vessels by conveyors, the machine illustrated could be employed by carrying the hopper over the hatch and feeding from the hold by a dredging elevator. There was a considerable difference between the two problems of loading and unloading, and were the vessel regularly engaged in this traffic, the saving of time and labour effected would justify the cost of handling plant being carried by the ship specially designed to suit the circumstances, in the same manner as at present it carried deck winches, etc.

Mr. A. **Smart** wrote that he ventured to suggest that the empirical formulæ given by Mr. Smith could be replaced, when the conveyance of minerals was being considered, by more rationalized formulæ. From information the writer had been able to find on belt-conveyors and from rational consideration of the subject, it would appear that the quantities, in cubic feet and in tons per hour, which could, in practice, be successfully conveyed on belts, would be given very nearly by the following formulæ :—

Volume conveyed per hour in cubic feet . $V = \frac{(B - M)^2 S}{2\cdot666}$

Weight conveyed per hour in tons . . $T = \frac{(B - M)^2 SG}{1478}$

These formulæ had been arrived at as follows:—

Let B = width of belt in inches.
,, R = radius of trough of belt in inches.
,, A = area of trough of belt in square feet.
,, K_a = coefficient for area of trough of belt so that $A = K_a B^2$.
,, S = speed of belt in feet per minute.
,, G = specific gravity of the material.
,, K_s = coefficient of solidity of the material conveyed—

$$= \frac{\text{Volume of the material in the solid}}{\text{Volume occupied by same material when broken}}.$$

,, M = size in inches of the material conveyed, that is, space between bars of screen or grizzley through which largest pieces pass.
,, K_f = efficiency for the evenness of the feed to the belt.
,, ω = weight in tons of one cubic foot of the material, as in bins or heaped (not in the solid).
,, V = volume in cubic feet conveyed per hour.
,, T = tons conveyed per hour.

Accepting the Author's proportion of radius of trough of belt to width of belt, which appeared to be a good proportion, namely,

$$R = \frac{B}{1 \cdot 3},$$

then

$$A = \left(\frac{B}{12}\right)^2 \times 0 \cdot 1002 = B^2 \frac{1 \cdot 002}{1440},$$

so that for all practical purposes—

$$K_a = \frac{1}{1440}.$$

The coefficient of solidity K_s varied with the regularity, or want of regularity, of the size of the material. If the material were broken, that is, the product of mining or quarrying operations, K_s would vary somewhat with the mode of fracture of the material. The more even the size and the greater the angularity of the material, the lower would be the value of K_s. On the other hand, the greater the variation in size and the more rounded the material, as for instance, water-worn gravel composed of all sizes

(Mr. A. Smart.)

from the largest down to fine sand, the greater would be the value of K_s. For the great majority of mineral conveying propositions, the coefficient of solidity K_s would be between 0·6 and 0·7. (It might here be remarked that if spheres of the same size were packed as closely as possible then $K_s = 0\cdot7405$). With fine dry free running sand, the mean area of the load on the belt would be a maximum, and it appeared safe to assume that the maximum could be 0·9 of the area of the trough of the belt.

As the proportion of the size of the material to the width of the belt increased, the greater would be the difficulty of feeding the material evenly on the belt. If it were practicable and economical to extend a belt-conveyor to miles in length, it would pay to design very elaborate arrangements to ensure the belt being continuously loaded to its maximum capacity. As, however, conveyor-belts rarely exceeded a few hundred feet in length, it was simpler and more economical, when the material was difficult to feed evenly on to the belt, to widen the belt to compensate for the unavoidable irregularity of the load. The coefficient $K_f = \frac{(B - M)^2}{B^2}$ appeared to agree well with what obtained in practice.

Working from the foregoing we get—

$$A = B^2 K_a = B^2 \times \frac{1}{1440}$$

$$V = 0\cdot9\ A\ K_f S \times 60 = B^2 \frac{(B - M)^2}{B^2} S \times \frac{0\cdot9 \times 60}{1440}$$

$$= (B - M)^2 S \times \frac{1}{26\cdot66}$$

$$\omega = \frac{62\cdot3 \times G \times K_s}{2240} = G K_s \frac{1}{36}$$

$$T = V\omega = (B - M)^2 S \frac{1}{26\cdot66} \times G K_s \frac{1}{36}$$

$$= (B - M)^2 K_s G S \times \frac{1}{960}.$$

If a mean value for $K_s = 0\cdot65$ be taken, then

$$T = (B - M)^2 G S \frac{1}{1478}.$$

Applying this last formula to belts 12 inches, 18 inches, 24 inches, 36 inches, and 48 inches wide, conveying material having a specific gravity in the solid of 2·5, and of sizes 0 inch, 1 inch, 2 inches, 4 inches, 8 inches, and 16 inches (the size 0 inch meaning, of course, that the material was so fine that the sizes of the particles composing it were so small that the size when inserted in the formula $K_f = \frac{(B - M)^2}{B^2}$ is negligible, and therefore $K_f = 1$) :—

M.	S.	12-inch.	18-inch.	24-inch.	36-inch.	48-inch.
Inch.		Tons.	Tons.	Tons.	Tons.	Tons.
0	300	73	164	292	658	1,169
	400	98	219	390	877	1,559
	500	122	274	487	1,096	1.949
1	300	61	146	268	622	1,121
	400	82	195	358	829	1,494
	500	102	244	447	1.036	1,868
2	300	51	130	245	587	1,074
	400	68	174	327	782	1,432
	500	85	217	409	978	1,790
4	300	32	100	203	520	982
	400	43	133	270	693	1,310
	500	54	166	338	866	1,637
8	300	—	—	130	398	812
	400	—	—	174	530	1,082
	500	—	—	217	663	1,353
16	300	—	—	—	—	520
	400	—	—	—	—	698
	500	—	—	—	—	866

Mr. W. L. SPENCE wrote that the Author referred to the locomotive and the steamship as primary transporters, but the writer was interested in a form of transporter much more primary than these, namely, the colliery underground coal-face belt-conveyor. This machine, developed under severely limiting conditions of size, weight, portability, and very rough usage, had attained a very large measure of success. The lowness of roof, often but little over 2 feet high, and the necessity for carrying large lumps of coal, had restricted the standard belt drum to 14 inches diameter, a size which involved

(Mr. W. L. Spence.)

high stresses in the $\frac{3}{8}$-inch thick belt. The conveyor, commonly 100 yards long, with a 600-foot belt and its driving gear, had to be moved bodily forward or sideways some 4, 5, or 6 feet every working day, hence the belt, sectionalized to facilitate handling, must be fitted with readily detachable hinge-joints. These hinge-joints running over 14-inch drums, formerly cut severely into the belt, but now with extremely large diameter hinge-pins or tubes, the joint-pin axis was so far lifted off the drum that the belt had a straight run out of the hinge-clip. The stretching trouble remained. A 20-inch wide belt had been known to stretch out to a 15-inch ultimate width in its fourth year, but this was unusual.

As to duty, the conveyor, with a 20-inch belt running at 100 feet per minute, was never the limiting element in output. The limit was either the coal available or the tram capacity at the discharge end. The conveyor would easily transport 180 tons per shift, and it had attained a ton a minute and 33$\frac{3}{4}$ tons an hour for 8 hours. The Author's maximum coal rating for this belt, hopper-fed, was 25 tons, and his average rating on unsized, run-of-mine coal, was 21 tons, so that the actual duty was not deficient.

In regard to belt-life, the 20-inch coal-face belts had a life of about 50,000 tons, and while it could not be expected to equal that of the Author's costly rubber-filled and faced belts, running under the best of conditions—perfect alignment, large pulleys and high speed—yet the difference was so great that it made one determine on a direct comparison of the solid-woven cotton with the rubber belt as suggested by the Author.

The one real refinement in coal-face conveyors, a feature in respect of which they were probably superior to any of the Author's gears, was the silent drive—a single-reduction duplex thrustless worm-gear of high efficiency. A silent gear was no useless refinement at the coal face ; it made for safety in enabling a cracking roof to be heard in the early stages. These characteristic features were mentioned because they all—size, weight, portability, and facilities—went to fit the conveyor for general cargo handling, as distinguished from the mass loading of grain or minerals, with which alone the Author dealt.

Experience seemed to indicate that conveyor capacity increased slightly more rapidly than as the square of belt width, and this seemed reasonable when it was considered that a small constant margin on each side of all belts of any width was dead. It was suggested to substitute for W^2 something of the form of $(W - 1)^2$, as representing capacity more accurately, thus :—

Belt Width (Gross).	W^2.	Ratio.	Belt Width (Net).	W_1^2.	Ratio.
Inches.					
20	400	1	20 – 1	361	1
30	900	2·25	30 – 1	841	2·33

The writer, an enthusiast for efficient worm-gearing, asked the Author to amend the three lines at the foot of page 87. No high-class power-transmitting worm-gear was self-sustaining; it was only badly designed power-transmission worm-gears that so acted.

Baron GEORGE STEINHEIL wrote that, with reference to the statement (page 78) about the oil-engines slowing down owing to the overloading of buckets, and even stopping sometimes, due to cooling of vaporizers, he thought this disadvantage could have been overcome if the fuel-pumps of these engines had been properly adjusted. It was accepted practice nowadays, when tuning up an oil-engine, to have the fuel-pump so adjusted as to deliver a certain maximum quantity of fuel into the cylinder and no more. This maximum was generally corresponding to 10 per cent or 15 per cent overload, and if the governor stopped working (weights in their inward position) due to an excessive overload, not more fuel was allowed to enter the cylinder than the predetermined maximum, thus obviating the danger of injecting an excessive amount of fuel, which could lead to an increased M.E.P. with consequent dangers of piston seizures, etc. In most cases an adjustable stop was provided, regulating the maximum length of the plunger's

(Baron George Steinheil.)

stroke, through the medium of the pump-handle. What really must have happened in the case mentioned by the Author, was that these engines either were not provided with such stops, or else they were out of adjustment. Because, if stops were properly adjusted, the engines would simply slow down due to the excessive load, and would continue to work at this rate, although their vaporizers would be hotter than at normal load.

In case of the stops being out of adjustment, the bigger the load, the more fuel was pumped into the cylinder, until a certain limit was reached when the amount of injected fuel was so large that it failed to explode, and it simply burnt and was eventually extinguished by incoming fresh charges, which soon cooled down the vaporizer of the engine with the resultant stoppage.. One could easily imagine the state of affairs inside the cylinder of this engine under these circumstances, due to excessive carbon deposits and washing away of lubricating oil from the cylinder walls. No engine, however well built, could stand such treatment for a long time.

Mr. ARTHUR R. WRIGHT wrote that one of the most interesting points in the Paper was the fact that the various large installations which were described were nearly all installations that had been erected out of England, and all erected by British firms. Several of the orders had been obtained for Great Britain in face of severe Continental and American competition, from which it followed that, although the American practice was generally believed to be so far in advance of the British practice, when it came to a question of competition on neutral ground, the British companies obtained the order.

The Durban coaling plant and the Han-Yeh-Ping unloading plant were typical instances. When these plants were required, most of the well-known American companies were quoting, but their offers were not considered by the purchaser to be as good as those put forward by the British companies. It was interesting to note that during the last few weeks a British company had obtained the order for an even larger plant than those described in the Paper, including unloading, storing and bunkering coal for China, in spite of full American competition, and he thought this augured well for the future of this country in machinery for the "Mechanical Loading of Ships," especially as the conditions in America had been such that they should have been in a position to offer more attractive propositions, if they had taken full advantage of their opportunities.

Mr. G. F. ZIMMER wrote that, with regard to the Author's remarks concerning the invention of the band-conveyor, he could not quite agree with him that the whole credit was due to Mr. Lyster. He was rather persuaded that the late Mr. Percy G. Westmacott (Past-President) must be credited with the lion's share of the pioneer work. He experimented for two years at Elswick, in the drawing office as well as in the engine works department, and concluded these investigations to his satisfaction in June 1868, the year in which the Mersey Dock and Harbour Board contemplated the erection of their extensive granaries, and the late Mr. G. F. Lyster, being the man at the helm, was undoubtedly responsible for the installation of these first band-conveyors for handling the grain at the Waterloo Dock. How far he shared in the invention, he (Mr. Zimmer) was unable to say.

In the discussion that followed Mr. Westmacott's Paper, read at the Newcastle-on-Tyne Meeting of this Institution in 1869, on the Waterloo Docks Granaries, Mr. Ramsbottom mentioned an earlier example of a band-conveyor, but as in this case the band was provided with scrapers which pushed or dragged the material along in a trough, and did not carry it, it could not have been what was now called a band-conveyor. Some early band-conveyors were, however, erected in two granaries on the Devaux System, one at Trieste and one at Canada Wharf in London. These were described in *Engineering*, 24 January 1868, that is, before the Waterloo Dock Granaries were erected; but it was quite likely, since Mr. Westmacott experimented for two years prior to 1868, that these were early applications of his idea. These band-conveyors delivered over the end, and had no throw-off carriages, the perfection of which latter

(Mr. G. F. Zimmer.)

must have been the greatest difficulty to Mr. Westmacott. A year or two ago the mechanical portion of these conveyors, minus the band, were still *in situ* at the Canada Wharf.

A. C. L. Devaux took out several patents for his system of granaries, the principal ones being dated 8 March 1856, and 22 July 1862, in neither of which band-conveyors were mentioned, while worm-conveyors were shown in the drawings ; and one would think that if this important invention of the band-conveyor had emanated from Devaux, he would have claimed protection for it in his granary patents.

As far as the writer's researches went into the history of the band-conveyor, the American millwright, Oliver Evans, who died in New York a little more than one hundred years ago (on 15 April 1819), was the inventor of a primitive form of band-conveyor. He built a flour mill in 1785, in which, in addition to band-conveyors, also worm and scraper or push-plate conveyors, as well as bucket elevators, were in use. In his book "The Young Millwright and Miller's Guide," first published in 1795, prototypes of all these principal continuous conveyors were illustrated and described.

Mr. F. T. PARKER wrote that he appreciated the difficulty Mr. Binns (page 111) had with belt specifications, but he was not alone in that respect. The writer was unable to follow whether Mr. Binns was speculating as to possible lines of development. The writer did not, however, agree that quay cranes had reached their limits, but he was with the speaker in his statement regarding the application of types to suit various conditions. Every type had its field.

Mr. C. Kemble Baldwin's comments were of interest. The Author's Table made it appear that an 8-ply belt, irrespective of width, would trough satisfactorily, which was not the case. The speaker rightly called attention to the Author's reversal of current practice in connexion with belt lengths. However, Mr. Baldwin would admit that those adopted by designers differed considerably. They were dependent upon individual choice, and the class of belt. The Author had doubtless taken this into consideration in his empirical formulæ. The lengths mentioned by the speaker were the exception, not the rule. Sometimes a client preferred to purchase his own belt. This often proved a source of annoyance to both parties, as occasionally inferior belts were used.

Mr. Baldwin mentioned some cases of belts in operation. If he had supplemented his information by giving the really essential details, such as the size of material, the feeding arrangements, the belt speeds and other governing factors, his statements would have been of service. All the details of the belt conveying 3,000 tons per hour were missing, even its size and speed. There was nothing remarkable about the Lake boats except, perhaps, their size, and British engineers years ago fitted steamers with unloading belts and had adapted elevators both for unloading and loading purposes. Dumpers were always a controversial subject, and it seemed useless to compare British and American practice. The problem hinged upon economic and local considerations.

Mr. Anderson (page 120), appeared to infer that retarding conveyors might have been considered for the Sebabna plant, but the ropeway was some miles in length. In this connexion, the writer would only install such a device as a last resort, even at these hillside mines, with which he was familiar. Regarding the angle of repose, the speaker might have given some indication as to what he would have expected it to be with dry and wet ore, as he will have noted the storage was an open one. Such instances had come within the writer's experience, and it was a moot point as to the best course to adopt. He noted the speaker suggested a portable chain-scraper, but if it had the effect of causing such a rush of material as he described, and the writer agreed it would, then it was the very thing to avoid. The Author distinctly mentioned two bunkers, one at the mine, the other at the loading station, and gravity was certainly not neglected. The writer referred the speaker to further remarks on capacity in his reply to Mr. Edwards. A ferro-concrete storage was not suitable for the purpose in view. The Author distinctly stated that 660 tons were loaded into the vessel in fifty-five minutes.

The writer would be glad to know where the "many plants" the speaker referred to were to be found, that is, of the bucket-

(Mr. F. T. Parker.)

conveyor type for open road work. The plant at Wabana was not on all fours. He thought Mr. Anderson's explanation of the movement of the cantilever the correct one, and had no doubt it was due to the action of an articulated chain of buckets passing over a tumbler at the extreme end. Those with dredging experience would quickly appreciate the surge brought about, and in the writer's opinion no form of equalizing gear would succeed in eliminating this. He concurred with the speaker's concluding remarks, and referred him to a written communication for the answer to his final comment.

In reply to Mr. F. G. Mitchell, he agreed the powers were high; they were for plain bearing idlers. The other points raised by him in connexion with the Author's Table he was unable to answer, but he appeared to take no exception to the Author's specification. The speaker also mentioned speeds, and no doubt referred to belt-conveyors. As he said, these speeds were high but safe, but the neglect to adopt them at times was not the fault of engineers. Local conditions played a part, and it was sometimes inadvisable to adopt too high a speed.

Dealing with Mr. W. S. Edwards' remarks, the fact that the stauffers did break off made it necessary for the Author to remedy the defect. The speaker raised the point as to whether, after the alteration had been made to the wheels, the plant at Sebabna ever attained its rated capacity of 800 tons per hour. In a recent issue of the *Cardiff Journal of Commerce*, it was stated that during the loading of a 3,600-ton steamer, an average rate of 825 tons per hour was maintained for four and a quarter hours. At one period 900 tons per hour were conveyed, but, owing to difficulty in discharging water ballast, the plant had to be slowed down. Whether the alterations to the wheels had anything to do with this, the writer was unable to say. Perhaps the ore was dry, and flowed freely. The writer had had these figures independently confirmed. Both speaker and Author agreed that a 48-inch belt running at 400 feet per minute would give better results; but there was a difference between "a far larger load," as stated by the former, and the Author's statement. Moreover, the former made certain stipulations, the significance of which must not be overlooked, whereas the Author did not.

The writer agreed it was impracticable to guarantee the life of a belt; and unreasonable to expect it. Such statements only led to trouble, and possible recrimination. If a purchaser was well advised in his choice of a belt, and the plant well erected and tended to, there was no reason why belts should not run for long periods. The Author's intention was evidently that of giving some indication of the life to be reasonably expected under favourable running conditions. The writer agreed with the Author's suggestion that, where possible, a belt should be flattened at the feeding end, but it was necessary to point out that this had to be very carefully carried out, and required space. In any case, Mr. Edwards surely would not introduce any form of auxiliary feeding apparatus, if it could be avoided. The introduction of worm-gears was inadvisable, but any form of check mechanism had to be thoroughly protected, to render its action effective. Solenoid brakes appeared to the writer to be the best method wherever possible of application. Mr. Edwards did not state what these "heavy stresses" were at the edge of a belt. They were not mentioned when discussing the merits of troughing idlers. They appeared to exist more in imagination than in fact, and the writer had a shrewd suspicion they would be difficult to establish with any degree of accuracy. As to Mr. Edwards preferring skirtboards at the bend pulleys, the writer did not agree. There was always risk of large pieces of material running awry, no matter how even the feed, and it was these pieces, not the smaller ones, that had to be looked after. Weightometers were guaranteed to weigh to within one-half of 1 per cent. The writer thought that the majority of our staiths would ultimately be provided with belt plants, as they were of light weight for their duty.

Dealing with the Manchester discussion, the writer disagreed with Mr. Fox's opening remark in par. 6 (page 132). So long as conditions would permit of belt installations, as at Hull, Fowey, Port Talbot, etc., nothing special was required, and if Mr. Fox

(Mr. F. T. Parker.)

provided a site, a number of firms would be found willing to install a plant, and possibly show greater savings in power, speed, etc., than with his existing machinery. The speaker, of course, referred to guide-idlers in the eighth par., and in the ninth par. expressed the opinion that grabbing was the most effective method. The writer agreed, but it remained to be seen whether it would develop along existing lines or otherwise. All things being equal, the grab transporter, as at present, might be in for a hard tussle. Part of the final paragraph was dealt with elsewhere, but the speaker mentioned self-equipped craft for bunkering steamers in rivers. So far as the writer's experience went, these were not an entire source of satisfaction.

Mr. Cecil Bentham (page 134) gave a lot of information, mostly well known to those acquainted with this class of plant, but generally dealing with grain conveying in docks. His opening remarks referred to cost and time. The writer was under the impression these were correlated. The Author made no mention of the numbers engaged, but the results at Han-Yeh-Ping were self-evident. Regarding his second paragraph, the speaker and Author were actually not at variance.

The Hulett and other grabs were quite well known. The speeds of belts mentioned for grain conveying were not remarkable, but when dealing with the life of belts, the speaker said that those conveying grain did not wear to "quite" the same extent. Why should they? If the speaker had not made an important omission as to the ply of belt used by him, the diameter of the driving pulleys mentioned would have been a check and of guidance. He also omitted to say whether these pulleys formed a single or multiple drive.

Mr. Bentham's comments on weighing were interesting, and he would find reference to the weightometer elsewhere. In spite of the fact that many tramp steamers did not carry load line charts, and that no weighing apparatus existed at some loading plants, the close results obtained by experienced hands in loading were sometimes remarkable. The writer had run out thirteen consecutive results obtained with a plant loading iron ore, without weighing, into steamers ranging from 2,800 to 5,800 tons, and found that the average actual weight established at port of arrival only exceeded the average given in the bills of lading by 0·3 per cent. The quarter of 1 per cent mentioned by the speaker was not for continuous loading, but the weightometer was.

The writer did not agree with Mr. W. G. Smith's comments on the Hull plant (page 140), as he himself obtained the order. There was a divergence of opinion within the gates, and the engineer responsible for the belt installation proved his point. It was not so much a question of convenience as of policy. The engineers at Durban preferred belts, besides which they desired to have the four tracks and an existing movable coaling transporter as a standby (*see* Fig. 2, Plate 3). Mr . Smith's remarks were in the main correct as to power consumption, although the writer believed it was nearer 300 b.h.p. as an average. He was also correct in respect to the dumper power. The reduction in speed was obtained at the dumper cradle. The Author cast no reflection, he merely pointed out the differences obtaining.

In reply to Mr. C. P. Kininmonth (page 142) he would find an explanation to his opening remarks immediately above, and it was necessary to state that the wharf was used as far as possible for coaling purposes. The writer merely speculated as to along what lines developments might take place. Shipowners both here and on the Continent realized long ago that the transport of iron and other ores was becoming a special trade, and the farther afield the steamers had to go for such cargo, the greater would be the necessity to deal with it rapidly. If a continuous and satisfactory system of unloading could be developed other than grabs or belt-plants, engineers would immediately turn their attention thereto, but although the speaker described two systems, he omitted to state whether these had been put into service, and with what results.

In reply to Mr. W. H. Atherton he could only state that all the plants were of British design and build. Large capacity belt installations would increase in number and importance. Given the same size and class of material, all other conditions being equal, it was easier to cope with the larger capacities, as the rate of hopper flow remained the same. The writer did not agree as to duplicate

(Mr. F. T. Parker.)

conveyors, as the extra first cost involved would be heavy. An outstanding feature of belt plants, given a suitable belt for the purpose, was their almost total immunity from stoppage due to breakdown. Bad damage to a belt was a rare occurrence ; there was usually ample warning, and repairs were rapidly effected. Conveyors, other than belt, were sometimes preferable, such as restricted space preventing the adoption of a suitable belt inclination, or where the characteristics of the material were unsuitable, as, for instance, hot substances. But where applicable, the belt held its own in regard to first cost, repairs, and maintenance.

Regarding the Sebabna buckets, the writer's recollection was that these were 42-inch pitch by 36 inches wide, dumping twenty-seven per minute, with a chain-speed of about 100 feet per minute. Further figures given on page 166 pointed to the actual bucket capacity being underestimated. There might also be another reason for the increased tonnage, namely, a spell of fine weather, and a consequently easier flow from the open ore-bins. Deep water conditions at Sebabna did not permit of steamers being moored other than at the end of the cantilever.

It was stated in *Engineering* (17 Aug. 1917), that the 48-inch belt at Durban was designed for 200 and 1,000 tons per hour at 120 and 600 feet per minute respectively. The contract amounts were stated to be 200 and 600 tons per hour at these speeds. The idlers being of the five-shaft six-pulley type, the troughing was shallow, and as the speed was variable, Mr. Atherton's well-put points were met.

Mr. J. M. Henderson (page 149) referred to an installation at Sadouna, while the writer mentioned one at Cherchell. These were one and the same.

Mr. F. G. Mitchell's communication (page 151) cleared up a point in the Paper in regard to the weights of the moving parts at Han-Yeh-Ping, which had led to some misapprehension. Other remarks emphasized the fact that British engineers were well abreast of the times.

Mr. W. H. Patchell stated that the Paper had suffered by curtailment. This had doubtless caused a little ambiguity in the phrasing adopted in the Author's Table, to which the writer would again refer.

In reply to Mr. T. M. Ritchie's remarks (page 154), portable conveyors were not new. In 1906, the writer was interested in the design of a portable telescopic conveyor to handle run-of-mine coal. The mast was not a new feature. The writer noted the conveyor handled rock phosphate up an angle of 30°. He presumed the conveyors were belt, and, if so, Mr. Ritchie was to be congratulated on having succeeded in conveying at an angle generally considered to be excessive. The writer's experience with Algerian and Tunisian rock phosphates had been less successful, and closely approximated results elsewhere.

Referring to Mr. A. Smart's contribution (page 156), it was one of considerable importance. The Author, not without success, had dealt with the question of belt capacities on common-sense lines, working back from actual results, until he had arrived at empirical formulæ. Mr. Smart had gone further, and his formulæ were applicable to all sizes of material. He made an allowance for evenness of feed. As this also included attendance, it was, to some extent, dependent upon individual judgment and experience.

Mr. W. L. Spence (page 159) went from the loading of ships in open roads, to the loading of cars in mine roads, but his remarks led up to the possibilities of belts for general cargo handling. Belt plants also had their limitations. Other methods were being rapidly developed, meeting the varying conditions with greater flexibility in operation. If the nature of the goods to be conveyed was suitable, belts were of service, but further important considerations affected their choice for this particular work.

Baron Steinheil dealt with the engine trouble at Sebabna (page 161). He was unable to reply as to the design of the engine, but thought another explanation might be given. With varying loads, such as obtained with these plants, it was of the utmost importance to have ample power in hand. First cost was always kept down, and it was probable these engines were overloaded and unable to cope with fluctuations in the load.

Mr. Arthur R. Wright's communication (page 162) was timely

(Mr. F. T. Parker.)

and accurate, and should be made use of by our trade organizations.

The writer felt it incumbent upon himself to make a few remarks in conclusion, in view of the Author's absence. As suggested (page 128), a Table (page 173) was appended and called for the following comments :—

(1) All figures remained as in the original (pages 102–9).

(2) All calculations as to tonnage were referred to those in line marked A.

(3) The ratios of specific gravities adopted by the Author were made use of.

(4) The wording of the line marked A for coal, as well as the corresponding ones for rock and ore had been modified. First, because it was demonstrable that the results for coal were obtained by using formula 1 (page 103) with the constant 36. Secondly, because had the Author intended the results to mean " when loading mixed coal, no large lumps," clearly either the constants $Z=33$ or 30 would have been used. Thirdly, because the Author obviously could never have intended to convey that the maximum capacities given for the three classes of material were absolute. Apart from other considerations, the fact of his formulæ being empirical controverted any such assumption. Consequently, the writer had modified the wording.

An examination of most Tables, more often than not, emanating from interested sources, showed a marked divergence from the Author's results, but it would be found that the essentials were nearly always lacking. A consideration of " at the rate of " capacities per hour, coupled with other qualifying remarks, introduced wherever possible, and similar to that made by one of the speakers at the London meeting, led one to the conclusion that the results given in such Tables were not attainable under everyday working conditions. Freak performances referred to by the Author were those where the records not only failed to

Belt-Conveyors.

Data for selecting suitable size of Conveyor, based on preceding formulæ and conditions as follows:—

Coal: specific gravity 1·5; voids 42·3 per cent; weight per cubic foot, 54 lb.; volume 41·48 cubic feet per ton.
Rock: ,, 2·8; ,, 42·3 ,, ; ,, ,, 101 ,, ,, 22·2 ,, ,,
Iron Ore ,, 4·0; ,, 42·3 ,, ; ,, ,, 144 ,, ,, 15·55 ,, ,,
Weight of 1 cubic foot of water = 62·5 lb., so that (62·5 × 1·5) − 42·3 per cent = 54 lb. for coal per cubic feet, etc.
Ratios of Specific Gravities. Rock to Coal 1·867 to 1. Iron Ore to Coal 2·667 to 1.
Ratios of Specific Gravities and Constants Z referred to Line A. Constant for Line A is Z = 36.
Lump Coal $\frac{1 \times 24}{36} = 0{\cdot}667$. Lump Rock $\frac{1{\cdot}867 \times 22}{36} = 1{\cdot}141$. Lump Iron Ore $\frac{2{\cdot}667 \times 22}{36} = 1{\cdot}63$.

Maximum Capacities to be expected for Rock	A × 1·867	Tons per Hour.
,, ,, ,, Iron Ore	A × 2·667	
Average Capacity for Lump Coal	A × 0·667	
,, ,, ,, Rock	A × 1·141	
,, ,, ,, Iron Ore	A × 1·63	

Width of belt in inches	24	30	36	42	48	54	60
Speed of belt in feet per minute	300	350	400	450	500	500	500
A { Maximum capacity to be expected in tons per hour when loading washed nut coal and sharp dry sands. Constant Z = 36.	108	198	326	500	723	915	1130 } A
Max. h.p. required for each 100 feet of conveyor for Coal	3·5	5·3	7·7	10·7	14·3	16·9	19·6
Additional h.p. required for each 10 feet the load is elevated	1·4	2·6	4·2	6·5	9·3	11·8	14·6
Max. h.p. required for each 100 feet of conveyor for Rock	4·2	6·7	10·0	14·1	19·2	23·1	27·4
Additional h.p. required for each 10 feet the load is elevated	2·6	4·8	7·9	12·0	17·4	22·0	27·2
Max. h.p. required for each 100 feet of conveyor for Iron Ore	4·9	7·9	12·0	17·2	23·7	28·9	34·3
Additional h.p. for each 10 feet the load is elevated for Iron Ore	3·7	6·8	11·2	17·0	24·8	31·4	38·6

NOTE.—All other figures given in the Author's Table, etc., pages 102–109, remain as originally published.

(Mr. F. T. Parker.)

Comparative Table of Average Belt Capacities per Hour.

This Table is based upon all the Author's assumptions given in his Table (pages 102–9, and on page 173). The capacities appearing under his name below are as in the original.

Mr. Smart's figures (page 156) referred to the above become :—

Coal : $T = (B - M)^2 S \frac{1}{1103}$. *Rock* : $T = (B - M)^2 S \frac{1}{591}$. *Iron Ore* : $T = (B - M)^2 S \frac{1}{414}$.

For K_s refer to page 157.

Authority.	Sp. Gr.	K_s with 42·3 per cent. Voids.	Size of Belt.	24-inch.	30-inch.	36-inch.	42-inch.	48-inch.	54-inch.	60-inch.
			Speed, F.P.M.	300.	350.	400.	450.	500.	500.	500.
			Size of Cubes.	6-inch.	8-inch.	10-inch.	13-inch.	16-inch.	18-inch.	20-inch.
Author	1·5	57·7	Coal	72	132	217	333	482	610	754
	2·8	,,	Rock	124	226	371	568	825	1,044	1,290
	4	,,	Iron ore	177	322	530	812	1,178	1,492	1,842
A. Smart	1.5	,,	Coal	88	154	245	343	464	587	725
	2·8	,,	Rock	164	286	457	640	866	1,097	1,355
	4	,,	Iron ore	235	409	653	914	1,237	1,565	1,932
F. T. Parker	1·5	,,	Coal	72	136	238	368	537	660	825
	2·8	,,	Rock	133	252	444	696	1,004	1,295	1,545
	4	,,	Iron ore	190	360	633	983	1,432	1,850	2,200

give particulars whereby comparisons could be made, but also information as to the conditions under which the plants were being operated.

The plant at Bilbao, Fig. 4, Plate 4, was designed for 1,000 tons of ore per hour with a 36-inch belt at 500 feet per minute. It was stated that the belt had handled 1,500 tons per hour. No mention was made as to time, and nothing said as to average performance. In this case, the plant was such that a speed considerably in excess of that mentioned could probably be attained.

The 48-inch belt plant at Durban was an instance where amounts in excess of those stated had been conveyed, but it would be very interesting to know whether any quantity was guaranteed per hour, without qualification of any sort. If such a clause existed, a considerable trimming of sails probably took place.

The 42-inch belt plant at Hull was guaranteed, without qualification, to handle 500 tons of run-of-mine South Yorkshire coal per hour at about 450 feet per minute. It handled larger amounts for short periods. The guarantee was met by the closest application to design, and by skilful handling. These were important factors in its success, in the light of experience at that time.

The 36-inch belt plant referred to by the writer (page 145) was guaranteed to deliver 400 tons of ore per hour at about 300 feet per minute. The plant had averaged about 500 tons, and even attained 600 tons for a short period under very favourable conditions. Bad weather also played its part. The Tables referred to claimed that this size of belt was capable of delivering "at the rate of" a much larger amount, but the results mentioned pointed to sound judgment in the choice of the belt size, and the figures of the Author were certainly nearer the mark.

The tabulated results of the Author (pages 108–9, and 173) took into account the evenness of feed, changing over hatches, labour available, and other contingencies. They were arrived at over a wide range of plants operating under greatly differing conditions. The Tables referred to made no mention whatsoever of these considerations. His figures might, therefore, be accepted

(Mr. F. T. Parker.)

as giving some reasonable indication of the capacities to be expected, until such time as there was concrete evidence to the contrary. The conditions varied to such an extent, sometimes day by day, that no two engineers could be in complete accord, but a reference to the Comparative Table on page 174 would show that the Author's average capacities agreed more closely with those of Mr. Smart and the writer, than with the majority of other Tables. This Comparative Table should be of service, as the three sets of figures had been arrived at from different view-points. The first two had been dealt with; the last was based upon the theoretical volume. All figures were upon the Author's assumptions (pages 102–109 and 173).

The writer regretted being unable to give further data based upon his own office and field work, owing to lack of time and space, but would say that while successes were heard of, failures were not unknown. Engineers could sift the evidence and draw their own conclusions. Those contemplating the purchase of such installations would also be in a better position to form a reasonable idea as to the returns likely to accrue on capital outlay. The Author had unquestionably rendered a service to the profession in drawing attention, amongst other things, to this question of belt performances, and it would need a considerable amount of explaining away. Finally, as the difficulties of introducing a Paper would be appreciated, the writer trusted any shortcomings would be overlooked in the handling of the Author's able and considered contribution.

THE MECHANICAL QUALITIES REQUIRED IN EYEBOLTS:

WITH SOME CONSIDERATION OF THE IZOD TEST, IN ITS RELATION TO THE QUESTION OF BRITTLENESS IN MILD STEEL.

BY R. T. ROLFE, F.I.C., OF THE METALLURGICAL RESEARCH LABORATORY,
MESSRS. W. H. ALLEN, SONS, AND CO., LTD., BEDFORD.

[*Selected for Publication.*]

The present Paper describes some work carried out on eyebolts, of which some were undoubtedly brittle, and others tough, under service conditions. The service brittleness appeared to be solely due to a low Izod figure in the material, and it was thought that the results should be put on record. No particular consideration had been given to the special mechanical qualities required in eyebolts, until the occurrence of several failures in the first batches of various different sizes supplied by outside stampers, which led to the rejection of the whole of the material, and its replacement by stampings of Messrs. W. H. Allen, Sons and Co.'s manufacture. With a view to finding why the "outside" eyebolts were defective, and in order to ensure that our own were not similarly brittle, a complete investigation was made. The sizes and details of the different kinds of outside eyebolts examined were as shown in Table 1 (page 178).

Nothing could be traced as to the behaviour of the 1-inch and $1\frac{1}{4}$ inch sizes. They were, however, as a precautionary measure, condemned with the others. It was considered that the Izod test should afford a ready means of discriminating between a tough and a brittle eyebolt, because it is an impact notch-test, in which the material is sheared. An eyebolt is notched (or threaded, which is the equivalent), and is often subjected to shock in service, while it was by shearing that all the failures recorded above took place. (Reference is made in the Table to failures in lifting fans, which are of such a design that the stress on the eye is lateral.)

TABLE 1.

Size.	Remarks.
¾ in. Whit. with 1 in. eye	Eyebolts of both these makes (two of each) broke in lifting 88-in. fans.
¾ ,, ,, ,, 1½ ,, ,,	
1 ,, ,, ,, 2 ,, ,,	No service data.
1¼ ,, ,, ,, 2¼ ,, ,,	No service data.
1½ ,, ,, ,, 3 ,, ,,	Broke while being tapped home into Dynamo magnet ring.

The Izod test was therefore applied to five eyebolts, one of each size, while of the same five, the analyses and microstructures were also determined. Another five, one of each size, were turned down to give tensile test-pieces, and a micro-examination and analysis was made of each, to establish the identity of the material with that on which the Izod tests were made, this procedure being adopted in every case where further bolts were taken. The results were as shown in Table 2.

The Izod test, as made in these and all the following experiments, was carried out on the round test-piece of the later Air Board specifications, that is, one of 0·45 inch diameter, notched down with a 45° tool to 0·33 inch at the bottom of the groove, radius 0·01 inch, and which is cut eccentric in a lathe. A 120 foot-lb. Avery machine was used. The microstructures of the above five bolts, which were photographed, are not here recorded.

Analyses of Outside Eyebolts.—It will be noted that some of these are rather high in sulphur and phosphorus. As will be seen by reference to the analysis results, given later, from some of Messrs.

Allen's eyebolts, this is, in itself, a quite insufficient explanation for the low Izod results.

TABLE 2.

Outside Eyebolts as Received.

Test No.	1	2	3	4	5	
Analysis.	1½-inch bolt.	1¼-inch bolt.	1-inch bolt.	¾-inch bolt with 1½-inch eye.	¾-inch bolt with 1-inch eye.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
Carbon . .	0·08	0·16	0·07	0·11	0·12	
Silicon . .	0·010	0·066	0·015	0·033	0·056	
Sulphur . .	0·087	0·036	0·076	0·051	0·049	
Phosphorus .	0·070	0·020	0·059	0·020	0·043	
Manganese . .	0·37	0·55	0·66	0·41	0·72	
Izod results .	5 : 6 : 5	91 : 112 : 70	7 : 5 : 5	10 : 9	3 : 3 : 5 : 5	
Izod average .	5	91	6	9·5	4	
Izod: appearance of fracture	Coarsely crystalline	Fibrous	Coarsely crystalline	Coarsely crystalline	Coarsely crystalline	
Dia. of test-piece, In.	0·505	0·505	0·505	0·282	0·282	0·282
Acting length, In.	1·75	1·75	1·75	1·0	1·0	1·0
Yield-point, Tons per sq. in.	17·5	19·5	18·2	20·8	8·0	14·5
Maximum stress, Tons per sq. in.	27·5	28·5	28·0	29·5	8·0 *	28·2 †
Elongation, Per cent.	36·0	35·0	36·0	31·2	0	31·2

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* Faulty. Broke where eye joins shank. † Re-test.

Macrostructures of Outside Eyebolts.—The macrostructures of sections through the eyebolts showed nothing unusual in the case of any of the five sizes. One from No. 4 (the ¾-inch bolt with 1½-inch eye), shown as Fig. 1, Plate 11, is a perfectly normal structure, and the same remark applies to that from No. 5 (the ¾-inch bolt with 1-inch eye), shown in Fig. 2.

TABLE 3.

Outside Eyebolts, Normalized.

Test No.	1n.	2n.	3n.	4n.	5n.
Size.	1½-inch bolt.	1¼-inch bolt.	1-inch bolt.	¾-inch bolt with 1½-inch eye.	¾-inch bolt with 1-inch eye.
Izod results . .	10 : 8 : 6	82 : 84 : 65	12 : 14	17 : 20	11 : 9
Izod average . .	8	77	13	18·5	10
Izod; appearance of fracture . .	Coarsely crystalline	Fibrous	Coarsely crystalline	Crystalline	Coarsely crystalline
Dia. of test-piece, In.	0·505	0·505	0·505	0·282	0·282
Acting length, In.	1·75	1·75	1·75	1·0	1·0
Yield-point, Tons per sq. in.	16·5	23·5	19·0	20·0	16·1
Ultimate stress, Tons per sq. in.	26·5	31·5	28·0	31·6	31·6
Elongation, Per cent.	34	28·6	34	30	30

Effect on Outside Eyebolts of Normalizing.—The results in Table 3 were obtained by normalizing at 870°–900° C.

The microstructures of the normalized bolts are not here recorded. The results of normalizing are thus slightly better in some cases, and slightly worse in others. The outstanding feature of both sets of tests is the high Izod figure of Eyebolt No. 2. A most important point is that the tensile test fails to discriminate between steels respectively tough and brittle under the Izod test.

For comparative purposes, the following results were obtained from the first four batches of the firm's own stampings put in hand to replace the rejected ones above :—

TABLE 4.

Own Eyebolts, Normalized.

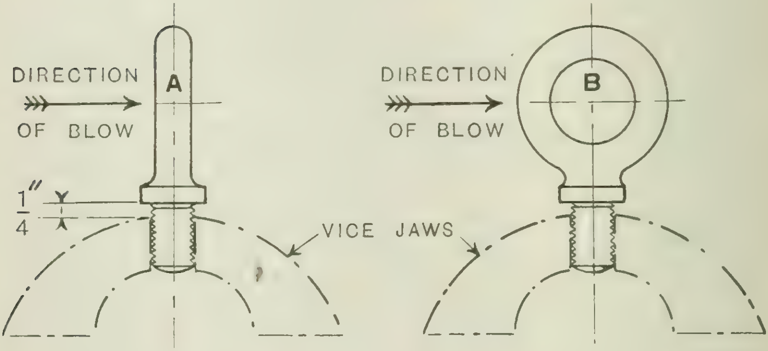
Test No.	**M1.**	**M2.**	**M3.**	**M4.**
Size.	$1\frac{1}{2}$-in. bolt.	$1\frac{1}{4}$-in. bolt.	1-in bolt.	$\frac{3}{4}$-in. bolt.
	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	0·18	0·28	0·18	0·32
Silicon	0·165	0·113	0·135	0·117
Sulphur . . .	0·046	0·045	0·085	0·065
Phosphorus . .	0·047	0·037	0·044	0·038
Manganese . .	0·44	0·60	0·82	0·55
Izod results . .	55 : 43 : 75	26 : 26	48 : 61	30 : 37 : 33 : 30
Izod average . .	58	26	54	32
Izod ; appearance of fracture.	Duplex ; core fine	Duplex ; core medium	Duplex ; core fine	Duplex ; core medium
Dia. of test-piece, In.	0·798	0·798	0·505	0·798
Acting length, In.	3·0	3·0	1·75	3·0
Yield-point Tons per sq. in.	16·8	18·4	23·0	21·8
Ultimate stress, Tons per sq. in.	29·2	31·0	30·5	41·0
Elongation, Per cent.	30·0	31·2	21·4	22·9

The microstructures of these were photographed, but are not here recorded.

Analyses of Eyebolts.—These should be contrasted with those of the outside eyebolts previously given, in relation to the Izod figures. It is quite impossible to explain the vastly different Izod figures by reference to the sulphur and phosphorus figures. The factor on which the Izod figure most depends is the carbon content, and this is referred to more fully later.

The next step was to correlate these different compositions, microstructures and mechanical test results, with the service behaviour of the materials. Imitated service tests were therefore carried out as follows :—

Fig. 3.—*Sketch showing Position of Eyebolt in Vice Jaws when subjected to a series of hammer blows.*



Imitated Service Tests.—In these the eyebolt under test was held in a vice and struck by hand with a 14-lb. hammer, either as A or B (*see* Fig. 3 above). Five blows were given as A, and if fracture did not take place, five additional blows were given as B, followed by further blows as A again. A criticism may be raised of this test, as regards variation in the constancy of the blows. In the opinion of the Author, the exact force of blow is not important, the intention being to find out whether the bolt broke or bent. A brittle eyebolt may be made to shear readily with a light blow, whereas a tough one under repeated blows bends through a considerable angle without breaking.

The results detailed below were obtained :—

Imitated Service Tests, First Series :—

¾-inch Eyebolts only, as follows :—No. 5—Outside, with 1-inch eye.
No. 4— ,, ,, 1½ ,, ,,
No. M4—Our own make.

TABLE 5.

Eyebolt.	No. of Blows given as		Remarks.
	A.	B.	
5 (first bolt) . .	1	—	Broke at first blow. No bend. Very coarse fracture.
5 (second bolt) .	3	—	Broke at third blow. The same remarks apply.
5 (third bolt) . .	3	—	Exactly as last.
4 (first bolt) . .	4	—	Broke at fourth blow. Bent slightly at each blow. Fracture rather coarse.
4 (second bolt) .	2	—	Broke at second blow. No bend. Very coarse fracture.
4 (third bolt) . .	5	5	Stood up. Bent moderately well.
M4 (first bolt) . .	22	5	Stood up. Bent considerably.
M4 (second bolt) .	60	5	Stood up. Bent considerably.

The last two bolts could not be broken by any effort. Five out of the other six broke readily in the first few blows. On applying the same test to the 1-inch bolts, it was found impossible, owing to the large diameter, to break them. To enable the necessary discrimination to be made, all 1-inch, 1¼-inch, and 1½-inch bolts were therefore screwed down to $\frac{3}{4}$ inch, when the following results were obtained :—

Imitated Service Tests, Second Series.

Eyebolts used.	Outside Bolts.	Our own make.
1-in. bolt screwed to $\frac{3}{4}$ in. . .	No. 3	No. M3
$1\frac{1}{4}$-in. ,, ,, ,, . .	No. 2	No. M2
$1\frac{1}{2}$-in. ,, ,, ,, . .	No. 1	No. M1

TABLE 6.

Eyebolt.	Number of blows given as A	B	Result.	Remarks.
3 (first) .	2	—	Broke	No bend. Coarsely crystalline fracture.
3 (second) .	5 4 add.	5	Broke	Bent 10–15° in all. Fracture medium to coarse.
3 (third) .	2	·	Broke	Bent about the same. Fracture medium.
2 (first) .	2		Broke	Bent a little. Fracture fairly fine.
2 (second) .	5 8 add.	5	Stood up	Bent about 45° in all, when test had to be stopped.*
2 (third) .	5 8 add.	5	Stood up	Do.
2 (fourth) .	5 11 add.	5	Stood up	Do.
1 (first) .	1	—	Broke	No bend. Broke at first blow. Very coarsely crystalline fracture.
1 (second) .	2	—	Broke	Bent slightly. Very coarsely crystalline fracture.
M3 (first) .	5 6 add.	5	Broke	Bent in all 30°. Fracture fine.
M3 (second)	5 24 add.	5	Stood up	Bent about 45° in all, when test had to be stopped. No sign of failure.
M2 . .	5 6 add.	5	Stood up	Do.
M1 . .	5 7 add.	5	Stood up	Do.

---

* Owing to the collar of eyebolt impinging on vice jaws.

Considering the results as a whole, the eyebolts fall into two classes, as follows :—

TABLE 7.

—	Sizes 5, 4, 3 and 1.	Sizes 2, M4, M3, M2 and M1.
Under working tests	Brittle	Tough
25 ft.-lb. Izod Figure	Below	Above
0·15 per cent Carbon	All show figures below this	All show figures above this
Microstructure	All show coarse ferrite crystals	All show a fine pearlite-ferrite structure

It appeared that the four sizes condemned were made of very mild steel, structurally consisting largely of coarse-grained ferrite, with a little pearlite segregated to the boundaries. The ferrite, although very ductile under static stress, fractures readily under a rapidly-applied shear stress, and a ferritic steel, in the absence of an adequate reinforcement of pearlite, gives Izod figures which decrease as the grain size of the ferrite increases, because in a large crystal a cleavage plane runs for a greater distance before reaching a grain boundary. A decrease in the size of the ferrite grains and their reinforcement by a substantial skeleton of pearlite renders the propagation of a crack across the material much more difficult, with resultant rise in Izod figure. There is ample proof of this in the appearance of the outside eyebolts before and after normalizing, as in every case the microstructure affords a complete explanation for the respective rise or fall in the Izod figure.

The microstructure of No. 2 of the outside eyebolts and of all four sizes of our own manufacture, considered in the light of this evidence, were all quite satisfactory.

The following results (Table 8) were obtained from further batches of our own eyebolts, which were systematically examined in the same manner :—

TABLE 8.—*Further Results from our Eyebolts (Normalized).*

Test No.	M1 a.	M1 b.	M2 a.	M3 a.	M4 a.	M5.	M5 a.	M3 b.
Size.	$1\frac{1}{2}$ inch.	$1\frac{1}{2}$ inch.	$1\frac{1}{4}$ inch.	1 inch.	$\frac{3}{4}$ inch.	$\frac{1}{2}$ inch.	$\frac{1}{2}$ inch.	1 inch.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Carbon . .	0·15	0·21	0·25	0·30	0·21	0·30	0·31	0·29
Silicon . .	0·170	0·040	0·141	0·040	0·020	0·132	0·020	0·08
Sulphur . .	0·050	0·035	0·035	0·045	0·035	0·044	0·033	0·041
Phosphorus . .	0·040	0·042	0·049	0·065	0·066	0·047	0·018	0·085
Manganese . .	0·50	0·66	0·65	0·75	0·78	0·62	0·59	0·75
Izod results. .	53 : 47	28 : 27 : 27 : 30	20 : 20 : 20	50 : 47 : 43	38 : 59 : 59 : 50	32 : 28	36 : 43	9 : 11·5 : 8 : 10 12·5 : 13·5 : 8·3
Izod average .	50	28	20	47	51·5	30	39·5	9·4
Izod : appearance of fracture	Duplex; core fine	Duplex; core moderately fine	Duplex; core medium	Duplex; core fine	Duplex; core fine	Duplex; core medium	Duplex; core medium	Medium; crystallined all over
Dia. of test-piece, in.	0·505	0·798	0·798	0·798	0·798	0·505	0·564	0·564
Acting length, in.	1·75	3·0	3·0	3·0	3·0	1·75	2·0	2·0
Yield-point, Tons per sq. in.	18·0	20·2	19·6	21·7	21·9	24·5	21·0	26·4
Ultimate stress, Tons per sq in.	30·0	35·3	34·4	37·8	35·5	36·5	35·4	40·0
Elongation, Per cent.	35·0	22·0	25·0	25·0	30·0	30·0	32·0	25·0
Imitated Service Test.								
Bolt screwed to	$\frac{3}{4}$-in. Whit.	$\frac{3}{4}$-in. Whit.	$\frac{3}{4}$-in. Whit.	$\frac{3}{4}$-in. Whit.	$\frac{3}{4}$-in. Whit.	$\frac{1}{2}$-in. Whit.	$\frac{1}{2}$-in. Whit.	$\frac{3}{4}$-in. Whit.
Blows as A, Fig. 3	10	10	10	7	12	12	6	3
Blows as B, Fig. 3	5	5	5	5	5	5	5	—
Resulting Bend, degs.	45	15	20	15	30	45	30	$7\frac{1}{2}$
Remarks . .	Stood up	Stood up	Stood up	Stoop up	Stood up	Stood up	Stood up	Failed

It will be noted that the last result, caused apparently by a high phosphorus figure, was a very poor one, leading to the rejection of the batch.

It has been demonstrated that a reasonably good Izod figure must be obtained before a batch of bolts can be passed into service. In the light of one or two of the results, however, it would appear that another desideratum is some degree of rigidity, which will be obtained in steels having carbon figures of not below about 0·20 per cent. This further requirement is put forward in order to explain the slightly inferior behaviour under the imitated service tests shown by some of the steels having carbon figures below this, although showing good Izod figures. For example, one of the bolts of No. 2 (0·16 per cent carbon) actually broke, although the other three gave excellent results; while one of the bolts from No. M3 (0·18 per cent carbon) did not give a result quite as good as would from its Izod figure have been expected.

Steels containing in the region of 0·15 per cent of carbon thus appear at times to have a somewhat greater brittleness in service than their Izod values would lead one to expect, and the qualification in question should therefore be applied to steels on the lower limit of carbon content. Apart from this, it is clear that in detecting really brittle bolts, the Izod test is all that is necessary. As regards the upper limit of carbon content, the Izod figure begins to fall off at some point above 0·30 per cent of carbon, and the material with increasing carbon figure would rapidly become unsuitable. A little more work is necessary before one is able to fix definitely the upper limit.

Eyebolt Specification.—In view of the above, the following requirements should be laid down :—

Carbon content of steel, preferably not less than 0·20 per cent, or more than, say, 0·34 per cent. Izod figure preferably not less than 25 foot-lb., and certainly not less than 20 foot-lb. The requirements of this specification are generally met by steel complying with the Admiralty 31–35 ton steel specification, although a good deal of material which would pass the latter would be rejected by the former.

One of the outstanding features of this investigation, which the Author desires particularly to emphasize, is the correlation between the Izod figures and the microstructures. It has been often stated that very wide variations in notched-bar figures, either given by different parts of the same steel or obtained from steels of much the same compositions, are often found, for which the microstructure affords no explanation. This appears often true for alloy steels, for example, in regard to temper brittleness, but in carbon steels the reverse is the case. The reason for the differences in Izod figure often given by different notches on the same bar is usually shown by the microstructures, and this does not appear to be generally known.

Low Izod figures are generally associated with a coarse ferrite structure, inadequately reinforced by pearlite. High Izod figures are generally associated with a fine ferrite structure, sufficiently reinforced by pearlite.

From the fact that very similar ductility figures can be obtained from these two classes, it is clear that the ductility figures obtained in the tensile test are, as has been already shown, valueless in judging the quality of eyebolts. The natural deduction is that no test can be considered as fundamental, but that the reliability of any test must be estimated entirely by the service conditions under which the part has to operate.

The Author desires to express to Messrs. W. H. Allen, Sons & Co., Ltd., his thanks for their permission to publish the results detailed in this Paper.

The Paper is illustrated by Plate 11, one Fig. in the letterpress, and is accompanied by an Appendix.

APPENDIX.

The following additional results were obtained from still further batches of our own eyebolts, which were passed for service on their carbon and Izod figures, no imitated service tests being made.

For comparative purposes, however, the Sankey results from some of these have been included :—

TABLE 9.

Test No.	M1 c.	M1 d.	M2 b.	M3 c.	M4 b
Size.	1½ inch.	1½ inch,	1¼ inch.	1 inch.	¾ inch.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	0·200	0·26	0·25	0·29	0·33
Silicon	0·082	0·09	0·06	0·15	Tr.
Sulphur . . .	0·042	0·039	0·034	0·039	0·058
Phosphorus . .	0·049	0·045	0·028	0·030	0·055
Manganese . .	0·58	0·66	0·66	0·50	0·62
Izod results . .	84 : 74 : 77	40 : 35 : 39	39 : 41 : 40	39:54:34:33	30:31:30:29
Izod average . .	78	38	40	40	30
Dia. of test-piece, In.	0·798	0·798	0·725	0·798	0·798
Acting length, In.	3·0	3·0	2·48	3·0	3·0
Yield-point, Tons per sq. in.	21·0	22·1	14·6	20·9	23·1
Ultimate stress, Tons per sq. in.	31·8	33·2	35·9	34·0	39·2
Elongation, Per cent.	32·0	31·3	33·4	32·4	25·0
Sankey Test :					
No. of bends . .	49·5	—	57	40	29·5
Energy to fracture, ft.-lb.	3,072	—	4,120	3,125	2,462

GRADUATES' ASSOCIATION.

THE MANUFACTURE OF BRITISH ASSOCIATION SCREW-THREAD GAUGES.*

BY T. FARRANCE DAVEY, OF LONDON, *Graduate.*

[*Abridged.*]

During the War, owing to the demand for mass production and incidentally interchangeable work, gauges were used more than ever before. Amidst an infinite variety, screw-thread gauges stand predominant as regards difficulty of manufacture. These vary in diameter from, say, $\frac{1}{10}$th inch, or even less, up to 1 foot or so. The large sizes are more easily made than smaller ones, such as the British Association screw-threads. The British Association threads have been taken for the purposes of this Paper as they present greater difficulties, which even yet have not been overcome.

The tolerance allowed in the accuracy of the gauge is of the order of 0·0002 inch. This extreme accuracy is rendered necessary by the demand for interchangeable work. Screws, such as those used in R.A.F. turnbuckles, may be made in one factory while the nuts may be made in another. On assembling them they must fit with the accuracy necessary to ensure the maximum strength of the screw being obtained without the need for selection. This accuracy can be obtained to, say, 0·001 of an inch by means of suitable gauges, but these in their turn must be multiplied to facilitate inspection. As they cannot all be made in one factory, much smaller tolerances have to be imposed. Thus extremely accurate generating and measuring appliances have to be used.

The present Paper deals with: (1) design; (2) methods and apparatus used in measurement; (3) compensation and correction for errors in the lathe; (4) cutting tools; (5) lapping; (6) heat-treatment.

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* The Author has been awarded a Prize by the Council for this Paper, which was read on 8th March 1920, and has been selected for publication.

The screw-thread is dependent for its accuracy upon its various elements, which are intimately connected. These are full, core, and effective diameters, the crest, root, slope or flank, angle, groove, pitch, and the angle of rake.

Errors occur in all the elements. The full and core diameters may be too large or too small. The effective diameter may also be too large or too small, but it is dependent upon the angle. The pitch may have two errors, one a progressive and the other a periodic error. Crests and roots may be in error, adversely affecting full and core diameters. The angle of rake may be in error, affecting the effective diameter and the angle, but this error is not of common occurrence. Various other errors occur if the core and full diameter cylinders are not concentric. In order to measure these errors and elements various instruments are employed.

Micrometer microscopes of various designs will measure pitch, angle, full and core diameters, depth and effective diameter, but the crests and roots have to be examined by means of a projection apparatus, which projects a magnified image of the thread upon a screen, where it can be compared with accurately made diagrams of thread sections. Pitch, and full, core, and effective diameters can, however, be measured by other means. Special pitch measuring machines have been made, and by means of specially mounted micrometers and the use of vee pieces and cylinders of known size, the full, core, and effective diameters can be accurately measured.

Sources of error have to be compensated for. These, in the case of the measuring instruments, are eliminated, except for personal errors, by careful calibration with accurate standards. The lathe upon which the screws are generated will have a pitch error, the gears which have been generated upon another machine will also have a pitch error. These two combine to give a very probably varying pitch error for gauges of different pitch owing to the use of different gears. The errors of the lathe have therefore to be compensated for by specially-designed apparatus.

Tools for cutting the thread of plug-gauges are of the single point type, chasers being found difficult to make with any accuracy. Circular single point tools are also made. Circular topping tools for cutting the radius on the crest are used. In cutting with single point tools 0·0005 inch cuts were taken. It was found better to cut one flank at a time, as the pitch varied as the tool got worn, owing to the spoilt edge partly rubbing over the metal, instead of cutting, and so taking too much from the other flank.

Taps.—We have now to discuss means and methods for cutting ring-screw thread-gauges. In the larger types of ring-gauges it is possible to cut the thread, directly in the lathe, by means of a cutting tool similar to that used for the plug-gauges. In the case of small diameter gauges, say below $\frac{3}{8}$ inch diameter, this method cannot be used owing to the difficulty of making the tool of correct proportion and strength to prevent chattering. Recourse has therefore to be made to taps.

It was thought that perhaps some of the taps on the market might be of sufficient accuracy for, at any rate, rough tapping. To this end one or two makes were tested and gave the following results :—

2 B. A. Threads.	Angle Error.	Pitch Error.	Effective Diameter Error.
A 1	+ 9½°	– 0·07 m/m.	+ 0·051 m/m.
2	+ 7½°	– 0·05 m/m.	+ 0·010 m/m.
B 3	Fair, but would need too much alteration to be of use.		

It was therefore necessary to make complete sets of taps for all the gauges to be cut. At first the old method of having three taps was used, with the result that they broke on the slightest provocation. It was then decided that, although involving a tedious process initially, yet better results would be attained in the end if instead of having perhaps eighteen threads on a tap, three short taps of six threads were made in its place. Thus eventually a series of about nine taps was evolved.

Taking, for instance, the set of 2 B. A. taps the main points to notice are :—

(1) Each tap has a guiding piece in front which just fits into the hole cut by the previous tap, or in the case of the first tap into the hole left by the tapping drill.

(2) The core diameter remains low throughout the set, leaving metal on the crest, where considerable wear takes place in lapping.

(3) Up to the fourth tap the full diameter rises fairly rapidly, while the effective diameter remains low. Then in the 5th and 6th taps the full diameter increases only slightly, while the tap cuts the flanks of the thread. Thus the work is apportioned out to each tap so as to divide the work up as evenly as possible between them.

(4) A seventh tap practically finishes the crest of the gauge leaving it + 0·0002. On this tap a steadying thread was cut in front of the cutting tap. This made sure that the tap was cutting correctly on the crest. The angle of the tap was made large to prevent the tap, if of too long or too short a pitch, cutting a groove in the side.

These sets of taps were cut from silver steel, and after being hardened, polished and tempered were fluted in a grinding machine, but they had to be relieved by hand as no relieving attachment was available. For making the laps necessary for lapping plug gauges two more taps had to be made, both with sharp crests, one being standard and the other plus on the effective. In using taps it was found to be absolutely necessary to keep those in use for tapping brass separate from those for tapping steel, as, if used indiscriminately for both metals, they "seized up" and a fracture occurred. Evidently the two materials wore the cutting edge of the tool, each in a different manner giving the most effective cutting edge for the given material.

Lapping.—Lapping becomes a necessity even in soft-type gauges owing to the difficulty experienced in cutting a perfectly finished thread with a cutting tool. In the case of hardened gauges the need is much greater, due to errors arising in the hardening process. In order to remove these errors, a small amount of material must be left on the gauge, which after hardening can be removed as required. This is done by lapping with an abrasive, as a cutting tool would not cut the metal. Various types of thread grinding machines for the larger sizes have been made, but even with these lapping has to be resorted to in order to get the fine finish required. The laps necessary for both plug and ring gauges are:—

(1) For reducing the flanks and so the effective diameter.
(2) For reducing the full diameter and correcting the radius at the crest.
(3) For reducing the core diameter and correcting the radius at the root.
(4) For correcting the angle.
(5) For correcting the pitch.

The first lap consists of a correctly shaped thread slightly large on all dimensions in order to go on the plug, or small if to go in the ring-gauge, and should be shorter in length than the thread to be lapped to eliminate pitch error.

The second lap consists of a semi-circular groove of the correct radius. The third lap consists of a thread of correct full diameter, but low on the effective and core diameter. This is thus able to lap only the root of the gauge. The angle also is made small in order to lessen the effective diameter without affecting the radius.

If the angle has been distorted either by bad lapping or in hardening, it may be corrected by means of the fourth lap. In order to correct a thread with a short pitch, a long pitch lap must be used and must be longer than the threaded part of the gauge. For a long pitch thread a short pitch lap must be used, and here again the lap must be longer than the gauge in order to make any difference in the pitch. The lap should be about half as long again as the thread being lapped. It is possible, if the error in the pitch is small, to compensate for it by making the effective diameter small, but this error in the effective diameter of course has to be within the limits allowed.

Any error "e" in the pitch of B. A. threads is multiplied by 1·8 when transferred to the effective diameter. If this error can be allowed for, then the periodic error in the pitch of the gauge must not exceed $\pm \frac{e}{1\cdot 8}$. It is found that brass is far superior to mild steel or cast-iron for lapping purposes (although cast-iron is usually used for large gauges), because :—

(1) It is easy to tap.
(2) It is cut by the tap or the tool into a clean thread easily.
(3) The abrasive sinks into the metal easily.
(4) The shape of the thread is not so liable to distort as iron owing to the toughness of the brass.
(5) The scrap metal after being used is still valuable.

The lap should fit fairly tightly and the abrasive should be as fine as possible. Two hundred wash emery is used for lapping and rouge for obtaining a fine polish. These abrasives are lubricated with a mixture of machine and lard oil. Fine carborundum was found to be too coarse, and distorted the thread. The tendency with a large grain abrasive was to use a loose lap. The grains then found their way to the crest of the plug or the root of the ring-gauge by centrifugal force. Here, where the greatest speed of cutting occurred, the greatest wear resulted and hence a wide angle was obtained. The thread also became scratched.

Rings are rough lapped to shape after having been hardened, and are then carefully finished, being repeatedly tested with the test plugs after having been washed in petrol to clean them from abrasive. To obtain complete control of the gauges during the lapping process, a small breast drill was mounted horizontally on the bench and turned by hand. The laps after being used are marked A. B. C., etc., and are then only used for rough lapping owing to possible error in the lap due to wear, and are in time discarded. In very fine threads less than 4 B. A. it was found difficult to lower the core of the plug-gauge if high by means of the ordinary laps, so a knife-edge stoned to the correct radius was used.

Heat-Treatment.—It was found that silver steel was most suitable for these small gauges as it was made of suitable diameter, was finely finished and was uniform in structure, being free from cracks and impurities. However, it was found difficult to harden it without distortion. Tests were carried out on 2 B. A. and 4 B. A. plug gauge threads and it was found from the results that :

(1) The full diameter rose throughout the thread, but to a greater extent at the point of junction of the thread with the handle than at the other end.
(2) The same applied to the core diameter.
(3) Thus the pitch increases owing to a greater length of thread resulting due to the taper shape of the gauge.

(4) The effective diameter seems to be less at the back of the thread than at the front and decreases throughout the length of the gauge.

(5) This seems to imply that the angle at the back widens more than the angle at the front.

It is thus evident that the neck, at the point of junction of the gauge with the handle, increases distortion. Error is also due to inherent stresses in the material due to its manufacture. Stresses also arise in the cutting of the thread.

The first error may be diminished by turning off the surface of the steel and then annealing it by heating the metal to 780° or 800° C., and then allowing it to cool slowly in sawdust or bone charcoal to retain the carbon content requisite for hardening.

The second error, due to the cutting of the thread, may be eliminated to a great extent by annealing in a similar manner after rough cutting. The thread can then be finished and hardened. Sudden cooling, as by water, will distort the metal to a larger extent than will oil hardening. It was found that by tempering the hardened gauges their pitch decreased. It was also found that the pitch and other elements tended to contract as time elapsed after hardening.

The error varies also according to the manner in which they are hardened. If the gauge is plunged end on into the quenching medium, the pitch error is greater than that caused by plunging the gauge in side on, although by this method the gauge tends to bend. In hardening taps it is found that less error occurs if the taps are hardened before the flutes are made. These flutes are then ground, but care has to be taken not to soften the tap.

In attempting to obtain a correct pitch, the solution is not found in destroying the hardening error, but by making it as small as possible, and, knowing how much it is going to be, cutting a short pitch screw by means of the compensating device. On hardening, the pitch can then be made to rise to give correct pitch. This condition can be obtained by careful experiment with one of the batch of gauges in process of manufacture and carefully treating all in the batch in the same manner.

The Paper was illustrated by Lantern Slides.

The Institution of Mechanical Engineers.

UNVEILING AND DEDICATION OF THE WAR MEMORIAL.

17TH FEBRUARY 1921.

The Relatives of some of the Fallen with members of The Institution, numbering about 60, having assembled in the Meeting Hall of The Institution, Storey's Gate, London, on Thursday, 17th February 1921, at 5.0 o'clock p.m., the Order of Ceremony proceeded as follows :—

The Lord's Prayer was said by the Assembly, standing, followed by the Hymn " O God, our Help in ages past."

The PRESIDENT, Captain H. Riall Sankey, C.B., C.B.E., R.E., ret., then delivered a short Address, as follows :—

MY LORD BISHOP, LADIES AND GENTLEMEN,

We are met this afternoon on a very solemn occasion to unveil a Memorial to the memory of those members of our Institution who gave up their lives for their Country during the Great War. I feel it is a great honour and privilege to be able to address, as President of The Institution, a few words to their relatives and friends. Let us hope that the first acute feeling of loss has been lessened, and merged into a feeling of pride that theirs was the most glorious death that any man can die—to die for his Country. This Institution desires me to extend to the relatives and their friends its deepest sympathy.

The members of The Institution were quick to respond to the call of arms in 1914, and 1,400 of all grades joined the ranks of His Majesty's Forces. There can be no doubt that the education and training they received in order to fit them to be members of this Institution, and the experience they subsequently gained as members, were of the utmost use in helping them to carry out the various duties with which they were entrusted, and in no small measure assisted to lead to final victory. Eighty-seven of our members and one member of the staff made the Supreme Sacrifice, and they would not have had it otherwise. They were fighting for the right, and the right prevailed. Nevertheless, had we lost, our profound debt of gratitude and the honour and esteem in which we hold their names would have been the same.

I would like to have been able to say something about all those whose names appear on the Memorial Tablet, but time will obviously not permit. I will, therefore, only refer to a few.

First, Sir Frederick Donaldson : he was President of this Institution for two years in 1913 and 1914 ; he occupied many important posts during his long and strenuous career, the last of which was as a Member of the Staff of Lord Kitchener on the mission to Russia. He lost his life in the sinking of H.M.S. "Hampshire" on 5th June 1916. We on the Council had the greatest respect, admiration, and affection for Sir Frederick, and his death was a serious loss to us.

Leslie Stephen Robertson accompanied Sir Frederick and lost his life on the same occasion. He was a well-known Engineer, and left many friends to mourn his loss. His work as Secretary of The Engineering Standards Committee was of the greatest importance. It was very near his heart, and it is a work which has been of the utmost value to the Engineering profession in this country.

Professor Bertram Hopkinson was also a well-known Engineer and an authority on all matters connected with Internal-Combustion Engines. He was Principal of the Engineering Laboratories at Cambridge, which were founded in memory of his father, Dr. John Hopkinson. He joined the Air Force and was killed whilst flying.

The other names we must pass over in silence, but we may be sure that had they been spared they would have made a success of their profession, and many would have risen to eminence. Nevertheless their death was of greater value to the country, and we can be quite sure that they and others have prevented this country—this British Empire of ours—from being under the domination of Germany. Let us do homage to our Glorious Dead.

The Assembly, having adjourned to the Entrance Hall, Prayer was offered by the Dean of Westminster (The Right Rev. Bishop Ryle, K.C.V.O., D.D.), and the President unveiled the Memorial Tablet, after which the Dean dedicated the Memorial and pronounced the Blessing.

The Hymn "The Saints of God! their conflict past" was then sung, followed by the "Last Post" sounded by Buglers, which concluded the Ceremony.

The Inscription on the Memorial is as follows:—

OUR GLORIOUS DEAD

1914-1919.

ADAMS, DUDLEY
ANDREWS, G. L.
ANDREWS, H. G.
ARMSTRONG, P. T.
ARMSTRONG, W. K.
BARNES, E. E.
BARRETT, E. B.
BARSTOW, M. W.
BRUCE, A. C. A.
BUCKTON, A. S.
BUMPUS, B. E.
BUSK, E. T.
CABLE, G. P.
CASSON, WILLIAM
CORFE, A. W.
COUSIN, A. N.
CRICHTON, J. A.
CROFTON, E. V. M.
CUNNINGHAM, F. L.
DAVIDSON, J. S.
DEAKIN, G. W.
DOMLEO, R. F.
DONALDSON, H. F.
DOUGLASS, P. C. D.
DRUITT, C. L.
ELLIS, H. D.
GILBERT, DAVID
GOODEVE, T. E.
GORDON, VIVIAN
GORT, A. H.
GRIFFITHS, R. S.
GRIMWOOD, B. C. R.
HAILE, EDWARD
HALL, G. S.
HALL, W. B.
HANDCOCK, R. H.
HARRIS, L. A. P.
HARRISON, D. R. D.
HARVEY, W. C.
HATTON, R. A.
HEWSON, C. L. B.
HOLLINGSWORTH, FREDK.
HOPKINSON, BERTRAM
HOWARTH, JOHN
INCHLEY, WILLIAM
JAMES, W. D.
JOHNSTON, A. D.
KENNEDY, CHARLES
KEYMS, T. B.
LANGDON, D. E.
LILEY, H. D.
MACAULAY, M. S.

McGROARTY, R. D.
McNAUGHTON, R. M. C.
MANISTY, H. S.
MANNING, G. A.
MAUNSELL, R. G. F.
NEILSON, A. M.
NORTHCOTT, H. H. M.
OKEY, W. E.
PARSONS, B. F.
POYNTING, ARTHUR
REED, F. H.
REYNOLDS, W. A.
ROBB, H. B.
ROBERTSON, L. S.
ROBERTSON, R. S.
ST. LEGIER, A. S. DE
SCHNEIDER, H. H.
SCOTCHER, W. G.
SHIRLEY, F. L.
SPINK, R. J.
STEPHENS, H. G.
TAYLOR, C. G.
TEBBUTT, O. N.
THOMAS, J. V.
THORNE, G. S.
TREMEARNE, W. C.
VANDELL, H. I.
VENNING, T. A.
VYALL, L. E.
WALKER, R. H.
WELSH, A. R.
WILKINS, F. T.
WILSON, JOHN
WILSON, L. H.
WORSSAM, L. H.
Staff: NEWTON, EDWARD

A photograph of the Memorial will be found on Plate 12.

The Institution of Mechanical Engineers.

PROCEEDINGS.

ANNUAL GENERAL MEETING.

FEBRUARY 1921.

The SEVENTY-FOURTH ANNUAL GENERAL MEETING was held at The Institution, London, on Friday, 18th February 1921, at Six o'clock p.m.; Captain H. RIALL SANKEY, C.B., C.B.E., R.E., ret., *President*, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the following 76 Candidates had been duly elected:—

MEMBER.

BIRCH, Jacob,	London.

ASSOCIATE MEMBERS.

ANGLES, John William,	West Hartlepool.
BOSE, Naba Kumar,	Jamalpur.
BROWNE, Oswald Henry,	Hyderabad.
BUTTERFIELD, Harry Vernon,	Cairo.
CODNER, William Hubert,	Colchester.
COLLINS, John,	Sheffield.
CUMMING, John,	Umballa.
DAVIES, Arthur Everitt Val,	Cape Town.
DOWDEN, Percy Pellatt, Lieut.-Col., R.A.S.C.,	Cologne.
EDGER, Harry Alexander,	London.
FARRAR, George Edward,	Kew.
GOONEWARDENE, Don Antony,	Colombo.
GUTTERIDGE, Hal,	London.

Haywood, Charles,	Nairobi.
Hedley, John Fenwick,	Sheffield.
Jenkins, Charles Edmund,	Kedah.
Jensen, Axel Emil,	Johannesburg.
Leonard, Lionel Douglas,	Derby.
London, Henry Michael Ainsworth,	Newcastle-on-Tyne.
Moon, Hubert Peter,	London.
Musgrave, John,	Manchester.
Newling, Walter Pickworth,	Abingdon-on-Thames.
Pontet, Henry,	Minatitlan.
Richards, Thomas Henry,	London.
Robinson, George Holroyd,	Enfield Lock.
Rose, Sydney,	Lincoln.
Symonds, John Charters, Major, R.A.S.C.,	Cologne.
Taffs, Cecil Willoughby James,	London.
Trigle, Sidney Edward,	Portsmouth.
Wadams, Samuel James,	Derby.
Willcox, Christopher Watson,	London.

ASSOCIATE.

Cadman, Claude Greener,	Kuala Lumpur.

GRADUATES.

Allcock, Harold John,	Cardiff.
Austin, Percy Ellis,	London.
Bamber, Graham Robert,	Manchester.
Bonnyman, George Alexander,	London.
Booth, Tom Askew,	London.
Cardwell, Edwin,	Newcastle-on-Tyne.
Clarke, Arthur Gibson Robert,	London.
Dalgliesh, David,	London.
Dixon, Donald Morgan,	London.
Eldridge, Tilden Theodore,	London.
Goodman, Hugh Frederick,	London.
Gower, Godfrey Philip,	London.
Grieve, James Alexander Walker.	Glasgow.
Hockley, Horace Reginald,	London.
Hollands, Herbert William,	Bilston.
Islip, Percy Cuthbert,	London.
Jennings, Harold Auguste,	London.
Judd, Clifford Hall,	Hampton Hill.
Keep, Herbert Stanley,	Hitchin.
Knight, Robert Duncan,	Weybridge.
Lindsay, Wallace Gordon,	London.
Mansell, Arthur George,	London.
Metcalf, Bernard Leslie,	Glasgow.
Metcalf, Henry Kenneth,	Glasgow.
Munro, William Thomas,	London.
Panton, Sydney Joseph Armitage,	Derby.
Peck, John Frederick,	London.
Pilkington, Peter,	London.
Pitt, George Albert,	London.
Preston, John Scott,	London.

Prior, Uriah John,	London.
Rayden, Raymond Georges,	London.
Ritchie, John,	London.
Ryves, Francis Donal Moncrieff,	London.
Scott, Harold Richard,	London.
Sparkes, William John,	Bristol.
Spencer, Charles Alfred,	Melton Mowbray.
Stuart, Macdonald Douglas Gilroy,	Bristol.
Thompson, Cecil,	Bristol.
Vaughan, Philip Beaumont,	London.
Whyte, Daniel,	London.
Wooding, James,	Bedford.
Wright, Philip Alan,	London.

The President announced that the following seven Transferences had been made :—

Associate Members to Members.

Bamford, William,	London.
Carosio, Giovanni,	Buenos Aires.
Pacey, Stewart Oswald,	Santos.
Spencer, Arthur John,	London.
Titren, Gerald Ernest de Keyser,	Johannesburg.
Walkem, George Alexander,	Vancouver.
Watts, Herbert Willie, Captain, R.E.,	Calcutta.

The Annual Report of the Council for the year 1920 was then presented, and taken as read.

The President said that in presenting the Accounts he would like to say that they had been prepared in the usual manner and according to the usual form, and it would be noticed that there was a debit balance of £6,349 19*s.* 3*d.* No doubt the members would desire some explanation of that debit balance. He would first point out that on the debtor side of the account there was a sum of £1,000 to be carried to the Debenture Sinking Fund, and that a like sum of £1,000 was to be carried to the Staff Pension Fund. Those amounts had therefore not left the Institution, but were merely transferred from one account to the other. That left the true excess of expenditure over revenue at £4,349 19*s.* 3*d.* The reason for that excess was first, that last year the revenue was on a pre-war basis,

(The President.)

because the recent increase in subscriptions had not taken effect—in the coming year that would bring in an increase of revenue which it was estimated would be approximately £4,000; secondly, the expenditure was on a post-war basis—the cost of everything had gone up seriously. To give only one instance, the increase in the printing bill alone was £5,500, which was more than the whole of the deficiency.

During 1915 it became evident to the Council that, with the commandeering of the Institution House by the Government and the receipt of a considerable rent for it, there lay before the Institution a period of restriction, not only of activities, but also of expenditure; and with the certainty of a surplus revenue it was the duty of the Council to conserve the funds against the days in an uncertain future. In 1916 a considered scheme of reserves was worked out by Mr. Mark Robinson, the Chairman of the Finance Committee. He would like to say that the Council and the members in general owed a great debt of gratitude to Mr. Mark Robinson for the care and foresight he had exercised in that matter. The scheme was approved by the Council in May, 1917. Apart from the larger funds created for more permanent and very necessary objects, a special fund was created under the name of "General Reserve," amounting to £18,061, formed expressly to meet the difficulties which would be met with in the post-war transition period which was now being experienced. By a resolution of the Council of the 18th May 1917, it was laid down that that fund should be "subject to such withdrawals as the Council might from time to time direct, whether for transfer to other reserve funds or for the current services of the Institution." In other words, that particular fund was to be, so far as the necessity might arise, a "carry-forward" from year to year, invested more profitably than being merely placed on deposit, but still a carry-forward until the war transition period should be completed, which should now be taken to mean until the year 1921 had ended, the economy of that year tested and its lessons learned. By a resolution of the Council, the debit balance would be taken from that fund.

The Council were determined that, without in any way detracting from the usefulness and the activities of the Institution, and especially of the Journal and the Proceedings, the expenditure should not continue to exceed the revenue, and with that object in view three special Committees had been formed with very definite references, to find out in what way expenditure could be reduced and at the same time efficiency maintained or even increased. He did not think there was anything further he could say on the accounts, and with regard to the remainder of the Report, dealing with the Research Committees and the various other Committees, the Report itself gave all the information that was required. If any members had any remarks to make on the Report he would be pleased to hear them.

Mr. G. W. Thompson inquired whether any members were on the special Committees mentioned by the President, or were they entirely composed of the Council ?

The President said they were Committees of the Council. He had no doubt that, if the Committees thought they could get any information from members generally, they would co-opt them or ask them to give evidence.

Mr. Thompson said he was pleased to hear the President say that the Committees would look into the question of finance, because it appeared to him that £29,000 was a very large item. Particularly he would draw attention to three items on the left-hand side—the reception, the dinner expenses, and the portrait of Dr. Unwin. Those three items altogether amounted to £1,000. Last year he asked particularly that there should be some retrenchment and the work carried on according to the revenue, and he was told that more money would be coming in. He had been pleased to hear the President's remarks, but he would point out that over £5,000 had been spent in printing, which meant that the volumes of Proceedings for the year were costing the Institution about 13*s*. 6*d*. He therefore moved " That a Committee be appointed comprising certain Members of the Council and certain Members and Associate Members."

Mr. P. S. PITT seconded the motion.

Mr. E. W. PETTER said before the vote was taken he would like to speak to the amendment. In view of the remarks that had been made by the President, he thought the committee that had been proposed by Mr. Thompson was entirely uncalled for. It was quite a usual thing, with the enormous increase in expenses which had overtaken everyone, both in business and in domestic life, for people to find themselves in a financial position such as had been disclosed by the accounts that evening. If the Council were not fully alive to the situation, there would be something to be said for the formation of such a committee as was proposed, but the Council recognized the position and had appointed special committees to deal with it. He thought he was right in saying that the subscriptions for 1920 of old members of the Institution had not been increased at all, and therefore the post-war work of the Institution had to be carried on with practically the pre-war income. That was really the thing the Council had had to meet. Although everyone regretted to see the adverse balance, he did not think any situation had arisen which made it necessary to form a committee of the sort suggested. He thought the matter could be quite safely left to be dealt with by the Council in the way that had been suggested by the President.

The PRESIDENT pointed out that a committee such as Mr. Thompson wished to have would be doing the same work as one or other or the whole three committees that had been appointed by the Council. As the question of those committees had been referred to, he would tell the meeting what they were. The first Committee would deal with the cost of the publications and the Journal, with printing, stationery and all such kindred matters. The second Committee would deal with the expenses of the Dinner, the Conversazione, and the Summer Meeting. The third Committee would devote itself to the question of research, as to whether it was possible to reduce the amount now being spent on research or possibly get other people to help in those researches. Those three Committees, he thought, covered the whole ground, and probably more ground than Mr. Thompson had in his mind. If another Committee was formed, in the way suggested by Mr. Thompson, it was getting near to a vote of want of confidence in the Council.

Dr. H. S. HELE-SHAW, F.R.S., Member of Council, said that the Institution always had been, and he hoped always would be, a self-governing body. In the election of the new Council, new blood had been introduced, and therefore it was only reasonable that the new Committees the President had mentioned should contain some of the new men who had come on the Council, and in that way the body of members was going to be thoroughly represented.

The PRESIDENT asked Mr. Thompson whether he would like to withdraw his motion.

Mr. G. W. THOMPSON said it was not in his mind to move a vote of want of confidence in the Council, and he was sorry if that impression had been formed. All he wanted was that the members should work in conjunction with the Council.

The PRESIDENT said Mr. Thompson obviously was not aware that quite a number of Committees had members on them who were not on the Council. It was as well for the members to know that, with the exception of a certain number of Committees which were Council Committees and which must be composed of Members of Council, as they dealt with matters which could not be made public generally, almost all the Committees had corporate members upon them. He asked whether Mr. Thompson would put his motion or withdraw it.

Mr. THOMPSON said he would let the motion stand.

Mr. P. S. PITT said he would still second it.

Mr. H. BATH SPENCER thought it was a wrong conclusion to

(Mr. H. Bath Spencer.)

take the proposal as being a vote of censure in any way on the Council. He himself took it as a sign of life in the Institution. There was only one time in the year when the members had a chance of asking questions and of expressing their opinions on matters which concerned the welfare of the Institution, and he was quite sure that all the members wished was that they should know exactly what was going on, so that they might take a live and keen interest in the work. It was not an unusual thing, especially when matters of finance came up, in the very special situation the country was in at the present time, for a Council to invite the assistance of the general body of members, and he thought that if some Members and Associate Members were co-opted on to the Committees it would meet Mr. Thompson's objection.

Mr. Mark H. Robinson, Vice-President, asked if it was understood that Mr. Thompson's proposed Committee was in effect a vote of censure upon the Council, though the only fault which it seemed possible to charge against the Council was that it had not raised the subscription early enough. The reason for that, if it was a fault, was that the wording of the Articles of Association made it difficult to augment the subscription revenue in much less than two years after the necessity for such a step had become apparent—in the present case by the completion, in 1919, of the accounts for 1918. The increase then seen to be necessary could not be submitted to an Annual General Meeting until Febuary 1920, nor take effect (except to a very small extent) until 1921. The Institution had been working on the old revenue, as the President had pointed out, though with greatly increased expenditure. In 1919 it was not possible to say what might happen in another year or two years; all the Council could do was to provide an ample carry-forward during the good times, so as to be ready for whatever might come. That was done. In the course of the next few months the Council would know more exactly what was going to happen, and they were taking the earliest possible means and the most drastic means of finding out what they could do to reduce expenditure in the future.

The President thought possibly the sense of the Meeting and also Mr. Thompson's view would be met if he said that the three Committees would be given power to co-opt.

Mr. Thompson said he was quite agreeable to that.

Mr. Pitt wished to know whether the Council would exercise that power.

The President stated the matter must be left to the Council.

Mr. G. D. Drewitt said he was rather in agreement with all that Mr. Thompson and other members had said about the very heavy expense in connexion with several items connected with the Journal, as, for instance, printing. He thought a considerable amount of money might be saved by putting the Journal out to tender to see what could be done. He thought Mr. Thompson's idea of having one or two younger members on the Committees, to see if it was possible that economies could be effected, was a good one, and he did not regard it in any way as a vote of censure.

The Motion for the adoption of the Annual Report was then put and carried unanimously.

The President said before the Paper and discussion were taken up, he would like to refer to the Benevolent Fund, the Annual Meeting of which would take place immediately after the present Meeting. Notwithstanding the many appeals that had been made, that Fund was not taken up by the members in the spirit which it deserved. There seemed to be a feeling that unless an annual subscription of a guinea could be given it was *infra dig.* to give anything at all. Obviously one guinea a year might be a very serious tax on the younger and less well paid members of the Institution, but why not subscribe 5*s*. or even 2*s*. 6*d*.? There were now 7,500 members, and if each of them were to subscribe 5*s*. the income would be £1,875, while at the present moment it was only £429. It was true that the demands on the Fund at present were not very great, but now was the time to build it up. Moreover, if the income were greater, many things could be done which could not be done now, most desirable things, such as paying the college fees or the apprenticeship expenses of the sons of widows of members. He hoped therefore that each member of the Institution would see his way to paying a small subscription, and he asked the members to take the matter into very serious consideration. It might be that some day the Benevolent Fund would be of advantage to some of those who were present that evening, and even if it were not, they would feel that they were helping the less fortunate members of the Institution.

The PRESIDENT then presented the following Prizes :—

The *Sir Robert Hadfield Prize*, 1921 : To Mr. H. MOORE, O.B.E., for his Paper on "A small Ball-Hardness Testing-Machine" (Proceedings, 1921, page 51).

Best Papers in the Graduates' Association : A prize of £5 to T. F. DAVEY for his Paper on "The Manufacture of British Association Screw-Thread Gauges" (page 191), and one of £3 to F. M. GREEN, for his Paper on "Modern Steam-Turbines."

Institution Examinations : A price of £5 to W. ABBOTT (Associate Membership Examination), and prizes of £3 each to W. H. MORRIS and A. C. PAGE (Graduateship Examination).

The PRESIDENT reported that the Ballot Lists for the election of Officers for the present year had been opened by a Committee of the Council, and that the following were found to be duly elected :—

President.

Captain H. RIALL SANKEY, C.B., C.B.E.,
R.E., ret., ... London.

Vice-Presidents.

Sir Robert A. Hadfield, Bart., D.Sc., D.Met., F.R.S.,	Sheffield.
H. S. Hele-Shaw, LL.D., D.Sc., F.R.S.,	London.

Members of Council.

H. I. Brackenbury, C.B.E.,	Newcastle-on-Tyne.
Alan E. L. Chorlton, C.B.E.,	London.
Lt.-Colonel A. E Davidson, D.S.O., R.E.,	London.
Sir Gerard A. Muntz, Bart.,	Birmingham.
Loughnan St. L. Pendred,	London.
William Reavell,	Ipswich.
T. E. Stanton, C.B.E., D.Sc., F.R.S.,	Teddington.

The President announced that the Council had made the following appointments to serve on the Council, under Article 23. They would retire at the next Annual General Meeting, and would be eligible for reappointment :—

Past-Presidents.

Edward Hopkinson, D.Sc., M.P.,	Manchester.
Michael Longridge, C.B.E.,	London.
William H. Maw, LL.D.,	London.
W. Cawthorne Unwin, LL.D., F.R.S.,	London.

Past-Vice-Presidents.

William H. Allen,	Bedford.
J. Rossiter Hoyle,	London.
Mark H. Robinson,	London.

The Council had also made the following appointments to fill the consequent vacancies in the Council. They would retire at the next Annual General Meeting, and would be eligible for election :—

Vice-Presidents.

Sir John Dewrance, K.B.E.,	London.
Sir Gerard A. Muntz, Bart.,	Birmingham.
William H. Patchell,	London.
Sir Vincent L. Raven, K.B.E.,	Darlington.

Members of Council.

L. A. Legros, O.B.E.,	London.
Frederick H. Livens,	Lincoln.
Ernest W. Petter,	London.
David E. Roberts,	Cardiff.

Chairmen of Local Branches.

Edward C. R. Marks,	Birmingham.
Lt.-Colonel E. Kitson Clark,	Leeds.
Charles Day,	Manchester.

The Council for the present year is therefore as follows :—

President.

Captain H. Riall Sankey, C.B., C.B.E., R.E., ret.,	London.

Past-Presidents.

Edward Hopkinson, D.Sc., M.P.,	Manchester.
Michael Longridge, C.B.E.,	London.
William H. Maw, LL.D.,	London.
W. Cawthorne Unwin, LL.D., F.R.S.,	London.

Past-Vice-Presidents.

William H. Allen,	Bedford.
J. Rossiter Hoyle,	London.
Mark H. Robinson,	London.

Vice-Presidents.

Sir John Dewrance, K.B.E.,	London.
Sir Robert A. Hadfield, Bart., D.Sc., D.Met., F.R.S.,	Sheffield.

H. S. Hele-Shaw, LL.D., D.Sc., F.R.S.,	London.
Sir Gerard A. Muntz, Bart.,	Birmingham
William H. Patchell,	London.
Sir Vincent L. Raven, K.B.E.,	Darlington.

Members of Council.

Daniel Adamson,	Hyde.
Richard W. Allen, C.B.E.,	Bedford.
H. I. Brackenbury, C.B.E.,	Newcastle-on-Tyne.
Sir George J. Carter, K.B.E.,	Birkenhead.
Alan E. L. Chorlton, C.B.E.,	London.
Professor William E. Dalby, F.R.S.,	London.
Lieut.-Colonel A. E. Davidson, D.S.O., R.E.,	London.
Sir Henry Fowler, K.B.E.,	Derby.
Henry A. Ivatt,	Hayward's Heath.
Christopher W. James,	London.
L. A. Legros, O.B.E.,	London.
Frederick H. Livens,	Lincoln.
Donald B. Morison,	Hartlepool.
Loughnan St. L. Pendred,	London.
Ernest W. Petter,	London.
William Reavell,	Ipswich.
David E. Roberts,	Cardiff.
George R. Sharpley,	Lincoln.
Thomas E. Stanton, C.B.E., D.Sc., F.R.S.,	Teddington.
William Taylor, O.B.E.,	Leicester.
Richard Williamson,	Workington.

Chairmen of Local Branches.

Birmingham	Edward C. R. Marks.
Leeds	Lieut.-Colonel E. Kitson Clark.
Manchester	Charles Day.

Mr. M. Holroyd Smith moved :—

> "That Mr. Raymond Crane, F.C.A., 46 and 47 London Wall, London, be reappointed to audit the accounts of the Institution for the present year at the remuneration of Eighty Guineas."

Mr. E. R. Dolby seconded the motion, which was carried unanimously.

The following Paper was presented by Mr. William H. Patchell, *Vice-President*, and discussed :—

> "The Desirability of Standardization in the Testing of Welds"; by F. M. Farmer, of New York.

The Meeting was adjourned at a Quarter to Eight o'clock. The attendance was 122 Members and 36 Visitors.

Mr. Farmer's Paper was also presented by Mr. Patchell at :—

> Manchester, in the Engineers' Club, on Thursday, 24th February; Mr. Daniel Adamson, *Member of Council*, in the Chair.

THE GENERATION OF STEAM.

LECTURE

BY SIR JOHN DEWRANCE, K.B.E., *Member of Council,*

AT THE GRADUATES' MEETING,

MONDAY, 14TH FEBRUARY, 1921, AT 7.0 P.M.

CAPTAIN H. RIALL SANKEY, C.B., C.B.E., R.E., RET., *President,*
in the Chair.

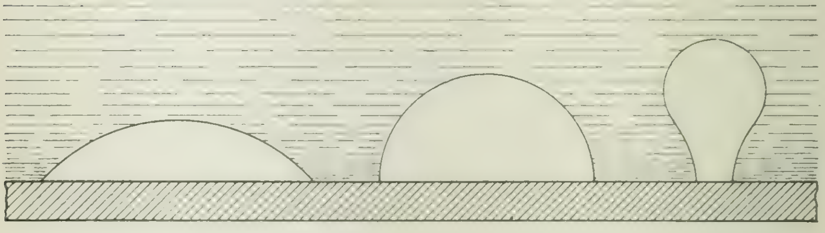
[*Abstract.*]

It has been suggested to me that the subject I have chosen is out of date and that internal-combustion engines are likely to interest you more than steam. It must be remembered that the world's output of coal is 1,250 million tons, and the output of oil is only about one-twelfth of that amount. The supply of oil is obtained mostly out of Britain, and is very little in excess of present requirements. The price of oil has of recent years risen in a much greater proportion than coal, and the price is still controlled in various ways. It is suggested by one inventor that the future engine will be a combination of oil and steam. Experiments are being carried out to use steam to inject oil into oil-engine cylinders.

The generation of steam is at present being studied by many inventors, with the object of utilizing much higher pressure than has been used in the past. A boiler was shown on the screen that could be supplied for pressures up to 500 lb., and another boiler to work up to 1,000 lb. pressure, The most efficient way of generating steam is to distil the coal or oil and burn the gas under water. One of the disadvantages of this method of generating steam is that the water in the boiler becomes very impure and corrosive. This demonstrates the paramount importance of keeping the water in a boiler as pure as possible. I do not propose to describe the various theories of the transmission of heat from the coal to the water; probably they are familiar to you.

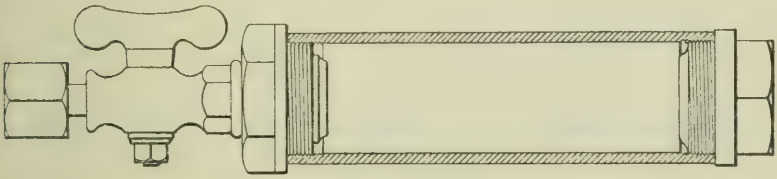
Water will absorb all the heat that can be transmitted by the greatest forge heat. I erected an experimental boiler to prove this. The tube was surrounded by a mixture of foundry coke and steam coal with a blast produced by a Roots blower. It melted the firebricks and evaporated 150 lb. of water per square foot of heating surface, but it did not injure the tube. An oxy-acetylene blowpipe, carefully adjusted, will impart to the tube more heat than the iron can conduct away to the water side, and the consequence is the iron is fused away from a small cavity. After a time, this action ceases and, on removing the blowpipe and carefully examining the cavity, it will be found that a microscopic hole has been fused through and water has cooled the point of the flame.

FIG. 1.



It must be accepted, then, that a clean plate will transmit to water all the heat applied to it in practice, and that if the plate is injured, it is because it is separated from the water by a layer of impurity, or steam has taken the place of the water. After the plate has transmitted to the water sufficient heat to bring it up to the boiling point, it can absorb no more, and the water that has previously been wetting the plate flashes into steam. If the plate is perfect and the conditions are suitable, a very large surface may be involved, but for my purpose we may suppose the bubble is as shown in Fig. 1. The slight superheating of the steam causes it to rise and form a circular free bubble, but in the process it assumes a balloon shape, and, if the heat is withdrawn, it will return to the previous shapes and again wet the plate. It will be readily appreciated that, if the water contains any impurity, it is left behind on the plate when the water is evaporated. If the pressure on the heating surface is increased by the height of the water level in the steam space being considerably above the heating surface, or by any other means, the water can absorb more heat without generating steam on the heating surface.

FIG. 2.



Corrosion Salt.—Corrosion and overheating are the two elements that limit the life of boilers in which steam is generated. Corrosion must be divided into three distinct causes :—

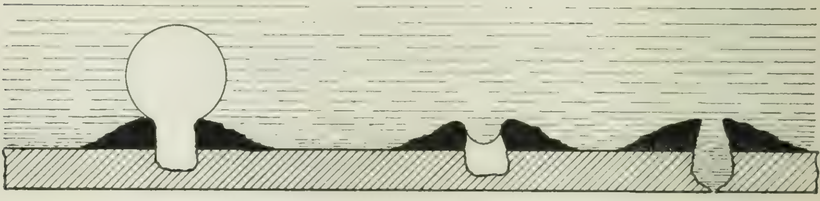
(1) Magnesium chloride.
(2) Air.
(3) Lubricant products.

The first is rarely met with in land waters, but the sea contains 0·364 per cent of magnesium chloride. If this is allowed to enter a boiler and is not properly broken up, it corrodes the heating surface and superheaters, but does not corrode parts that are not fire-heated. The magnesium chloride does not corrode whilst in solution. This was proved by putting concentrated sea-water, from a boiler that has been corroding, into a tube shown on Fig. 2. The steel tube was bored out and fitted with caps and a cock. The air was exhausted very carefully and the water half-filled the tube. The apparatus was put into a boiler that carried 300 lb. pressure per square inch for 74 hours, and lower pressures down to 130 lb. per square inch for 54 hours. At the end of this period the quantity of water was exactly the same and perfectly colourless, and the tube showed no sign of corrosion.

Sodium chloride is a stable salt and is not corrosive when in solution or when evaporated to dryness, but it produces hydrochloric acid at a red heat.

Magnesium chloride, on the other hand, is not corrosive when in solution but is broken up into hydrochloric acid and magnesia when evaporated to dryness at the temperature of boiling water. When the bubble is formed as shown on a heating surface, the magnesium chloride left behind is brought to dryness, and the last of the water combines with the chlorine, forming hydrochloric acid, and momentarily the acid etches the plate.

Fig. 3.



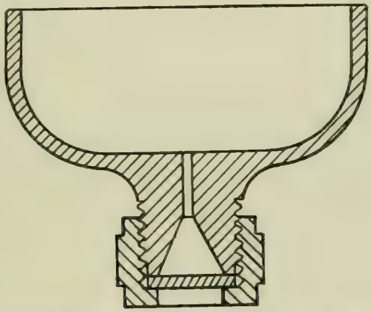
As the formation of steam bubbles generally takes place where the plate is indented, this etching process begins to form a pit-hole and oxide of iron is deposited around it. As the corrosion proceeds, the oxide ejected leaves an opening just large enough for the steam to escape. So long as the steam is escaping from the cavity no water can enter, and this accentuates the production of acid. Fig. 3 shows the progress of such a pit-hole.

The apparatus shown in Fig. 4 has been constructed by the Lecturer to demonstrate this action. A disk of steel is held in the base of a chamber, the outlet of which is small. By heating the disk, rapid corrosion is shown, and $\frac{1}{1000}$ of an inch is corroded away in two hours.

In the last century this form of corrosion destroyed marine boilers very rapidly, and rendered water-tube boilers quite unsuited for marine service. The cause of corrosion, other than air corrosion, was not understood, and a Commission was appointed, but did not succeed in discovering the cause or remedy. A research was then commenced in my laboratory, and I succeeded in explaining the cause and also the remedy.

Lime or soda added to the water in the boiler breaks up the magnesium chloride. By distilling the make-up water the proportion of salt can be reduced, but the priming of evaporators and the corrosion of the condenser tubes are liable at any time to introduce salt, so some apparatus is necessary in all marine boiler rooms to enable the engineer to deal with any salt that may come into his boiler. This discovery was published in a short Paper read before the Institution of Civil Engineers in February, 1900, and was discussed at three crowded Meetings of the Institution. The Author was awarded the Watt Gold Medal, and it is not too much to say that the knowledge then published has enabled engineers to increase the life of their marine boilers very greatly.

Fig. 4.



When sea-water is concentrated, say 4 times in an evaporator, hydrochloric acid is produced and the steam spaces are corroded, while the water itself is not acid. The explanation seems to be that bubbles containing steam and hydrochloric acid are formed, as explained above, and float up through the water. There is plenty of magnesia to neutralize the hydrochloric acid in the water, but the acid being contained in the bubble cannot combine with the magnesia, so attacks the iron in the steam-space and the steam-pipes from the evaporator.

When steam is generated, it is most important that it should leave the generator as free as possible from water. To effect this, a dry pipe is necessary, and though expensive, the very best form

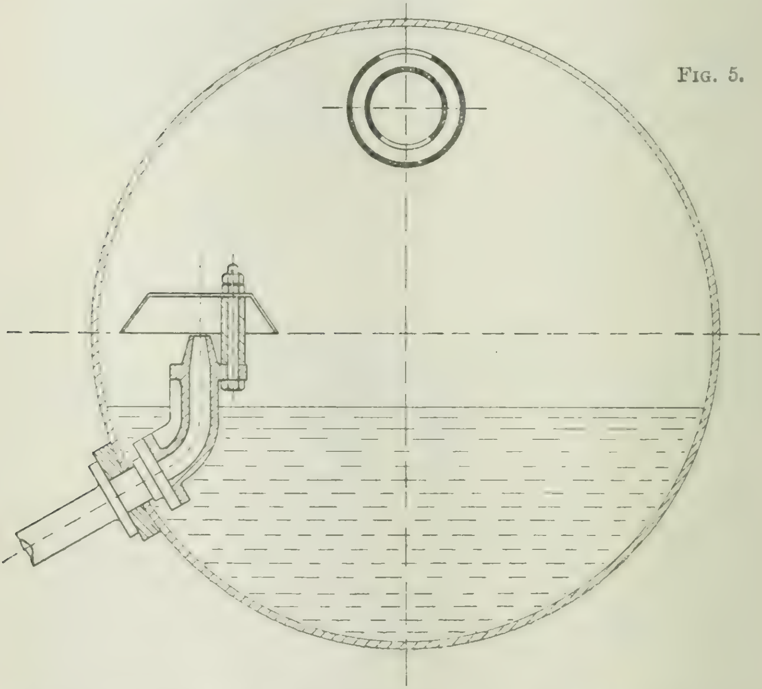


FIG. 5.

of dry pipe is justified. In the drum shown in Fig. 5 there is one inside the other. The outer pipe has saw-cuts at the top and the inner pipe has similar saw-cuts at the bottom to intercept any water. Such a dry pipe will raise the efficiency of a superheater very considerably, and is also a great safeguard of the superheater, especially at sea, because, if any magnesium chloride is carried into a superheater, it is converted into hydrochloric acid which corrodes the superheater.

Air.—The most universal, and perhaps the most difficult impurity of water, is air. Water dissolves air with surprising avidity. Feed-pumps, worked off the engine, pump large quantities of air into a boiler. Independent feed-pumps that cease pumping when there is no water, reduce this cause of corrosion. It is not always realized how rapidly air, dissolved in water, corrodes iron or steel. Even when the greatest care is employed to avoid the introduction of air into the boiler with the water, there is always some that is dissolved with the water and goes in with the feed. It would seem probable that as soon as the feed-water entered the boiler, this air would escape with the steam, but it does not. The way that gases escape from fluids is not fully understood. It is a very common experience that, when a tumbler of water is drawn from a tap and left for a few minutes, bubbles of air will form on the glass but not in the water itself. One cannot understand how the air in the centre of the tumbler knows that there is a convenient surface to escape upon. In the same way, in a boiler it seems that any air dissolved in the feed-water hunts about for surfaces of the boiler where corrosion has started, and go and escape there, instead of rising to the surface and the steam space.

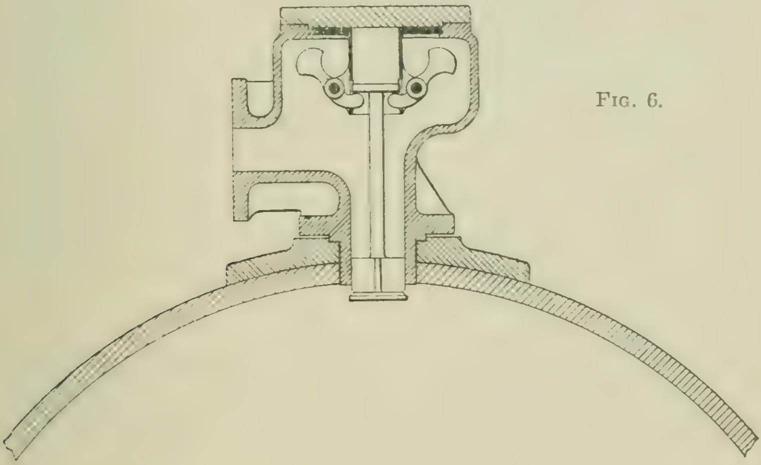


FIG. 6.

It would seem that the best way of freeing the air from the water is by spraying the feed into the steam-space. This has been tried on many occasions, but it has not been generally adopted, probably because water-hammer is very troublesome at the outlet. If there is a space of only a few inches length between the water-valve and the steam-space, it is sufficient to cause a water-hammer. The valve shown in Fig. 6 obviates this, and a loose cylinder may be added to prevent any spray being carried away to the steam-outlet.

Fig. 5 (page 220) shows another very convenient arrangement that has been largely used on marine boilers and has been successful in stopping air-corrosion. The internal pipe is fitted to the usual feed inlet, and sprays the water in the steam-space, liberating the air which is carried off with the steam. Some suitable variation of these arrangements ought to be fitted to all boilers, as at present most boilers suffer from air corrosion. The Institution is to have a Paper read before it on Degassing and Purification of Boiler-Feed Water, which will be of great interest and will throw further light on this important aspect of corrosion.

Oil.—The next impurity of water that gives trouble in all the best installations is oil. It is a great advantage of the turbine that it does not put so much oil into the boiler as a reciprocating engine. A pure mineral oil is less objectionable than an oil that is saponifiable, especially if there is any soda in the water. If in a vessel containing a small quantity of boiling water and soda, mineral oil be added, nothing happens. But if a little tallow is added, the water froths up immediately. Practically all priming is due to the formation of soap in the water in this way. A little tallow on the pump-plungers may cause serious priming. When oil, that will saponify in this way, is heated in a boiler, it forms acid in the same way as the magnesium chloride and corrodes the plate, but corrosion is not limited to the heating surface.

Another evil of oil is that it prevents the water wetting the heating surface. This experiment can be easily tried. If you incline a sheet of iron and heat it and drop water on to the hottest part, it is possible to establish a balance where the drops of water are just sufficient to keep the surface wetted. Pass a brush full of oil over the plate, and it is necessary to increase the number of drops per minute fifteen times before it will wet the plate.

When oil is mixed with lime scale, it makes it very impervious to water. Plumbago is now ground to such a degree of fineness that it remains suspended in water. In this form it should be a substitute for oil. It is now being tried as a cylinder lubricant for the pumps and auxiliary machinery where the steam goes to the condenser, and it might be suitable for lubricating piston-rods and packing glands. It can be supplied in a sight-feed lubricator using paraffin to drop through. A great deal of importance should be placed on any improvement that can keep oil out of the boilers.

I have dealt with corrosion under three heads—salt, air, and lubricants. If my belief is correct that steam will, in the future, be generated to much higher pressures, the construction of the boilers must be suitably developed, and they must be preserved from all forms of corrosion.

The Lecture was illustrated by 20 lantern slides, experimental apparatus and samples. This Abstract is illustrated by 6 Figs. in the letterpress.

THE DESIRABILITY OF STANDARDIZATION IN THE TESTING OF WELDS.

BY F. M. FARMER, OF THE AMERICAN BUREAU OF WELDING, NEW YORK.

Welding by gas and electrical means has long since passed the stage of small applications, and is becoming one of the more important of the mechanic arts employed in the manufacturing and fabrication of metallic structures. Although the welding art had been developing very rapidly, expansion was particularly rapid during the War because of the great possibilities for saving time and labour which were made evident. Since the War the field of application of welding has continued to expand, being accelerated no doubt by the ever-increasing economy over other methods of joining metals, which involve any considerable amount of labour.

No argument is needed for standardization as a general policy. Its value in most fields of human activity, and particularly in engineering, is generally acknowledged. Therefore, when a new art becomes an important element in industry, standardization is not only desirable, but is almost essential if development along sound engineering lines is to continue. That this view is recognized, is indicated by the fact that one of the important functions of the Bureau of Welding—an organization established by the American

Welding Society in co-operation with representatives of Government Departments and Technical Societies—is to standardize various phases of gas- and electric-welding, such, for example, as methods of welding, the training of welders, tests of welds, nomenclature, methods of inspecting and testing welds in completed structures, etc

So far as the Author is aware, no welding standards of any kind have yet been proposed in the United States, either by the Bureau of Welding or other authority. However, there has been considerable discussion of this phase of the welding situation, particularly by the Welding Research Committee of the Emergency Fleet Corporation, and as wide discussion is essential to progress in real standardization, this Paper is presented as a contribution to the subject of standardization in connexion with the testing of welds. Standards for evaluating welds are suggested, and certain standard procedures are proposed for those mechanical tests which the Author considers to be the more important. It is believed that a free discussion of the proposals from the standpoint of British practice will have a great influence in promoting standardization.

Need for Standardization in Testing Welds.—Standardization of the procedure in making a test of any kind is obviously necessary before results obtained by different observers can be compared. Tests of welds are no exception to this general rule. Differences in details of procedure have caused such widely divergent results that comparisons are frequently impossible, with the result that the usefulness of much of the research work on record is greatly restricted.

The great need, however, in welding is for some standardized method of measuring or determining the relative value of a weld. The ideal weld is presumably one which does not change the characteristics of a structure containing such a joint from those which the structure would have, if no joint had been necessary. In other words, the joint should have the same characteristics as the adjoining metal. If this view be correct, what tests should be made to determine these characteristics, and how is the degree of approximation of a weld to the ideal weld to be determined?

Standards for Testing Welds.

Fundamental Basis.—A weld is, in general, made for the purpose of joining together two pieces of metal in a structure. Joints are usually a necessary evil. They are avoided when it is possible to fabricate structures without them. The effectiveness of a joint is therefore determined by a comparison of the characteristics of that part of a structure containing the joint with a similar part which has no joint. Sometime in the future, processes may be developed which will produce welds having inherent characteristics, such that welds may be introduced into a structure for the sake of acquiring these characteristics. In that case the above basis of evaluation would not be applicable, but that time has not yet arrived. Also the argument has been advanced that because a weld is non-homogeneous, it cannot properly be compared with a homogeneous metal. While this is true as far as some characteristics are concerned, the fact remains that in the present stage of the art, welds are simply joints, and the practical basis of evaluation of a weld is in terms of the metal of the parts joined together.

Kinds of Standards.—It is obvious that for many purposes an investigation of a weld need not be extensive. There should be, therefore, several standards which will serve the more usual purposes. Three standards are suggested—shop standard, commercial standard, and research standard.

(*a*) *Shop Standard for Testing Welds.*—In the shop a standard test is required for such purposes as checking the work of a welder from time to time, testing a new lot of electrodes in electric welding or of welding wire in gas-welding, testing the effect of some change in conditions which may have taken place, etc. Such a standard must necessarily be as simple as possible and preferably a single test. The technique of the procedure in making the test must be of a simple character. For such a standard, a bending test is suggested. A bending test involves more of the important properties of a material than any other single static test, yields the most information, and can be made with very simple apparatus, (*b*) *Commercial Standard for Testing Welds.*—There are many cases where more than one kind of test should be made, but where the circumstances do not justify a complete investigation. There is, therefore, a need for what might be termed a commercial standard for making, for example, comparisons between different commercial welding processes or between different kinds of electrodes in electric metal arc-welding or different wires in gas-welding. It is suggested that such a standard should consist of three tests—a bending test, a tensile test, and a fatigue test. These three tests probably give more information than any other three tests that could be selected.

(*c*) *Research Standard for Testing Welds.*—When a complete investigation of a weld is to be made for research or other purposes, all tests and examinations are made which will contribute any information in regard to the characteristics of the weld. It may be necessary to make tests of a special character in special kinds of welds or where application under unusual conditions is contemplated, but there should be a standard list of tests which will give information which is complete, as far as all ordinary requirements are concerned, The following is suggested for such a standard list :—

A. *Tests of Base or Parent Metal :—*
  (1) Chemical analysis. To include carbon, manganese, silica, phosphorus, and sulphur.
  (2) Mechanical Tests :
    (*a*) Tensile. To include yield-point, ultimate strength, total elongation, and reduction of area.
    (*b*) Bending.
    (*c*) Fatigue.
  (3) Metallographic. Photomicrographs at 100 diameters.

B. *Test of Weld :—*
  (1) Mechanical tests :
    (*a*) Tensile. To include yield-point, ultimate strength total elongation, and reduction of area.
    (*b*) Bending.
    (*c*) Fatigue.
    (*d*) Impact.

(2) Metallographic. Photomicrographs at 100 diameters at (*a*) the junction between the base metal and the filled-in metal, (*b*) the base metal adjacent to the junction, (*c*) the centre of the filled-in metal.

C. *Tests of Filled-in Metal* :—

(1) Chemical analysis. To include carbon, manganese, silica, phosphorus, and sulphur.

(2) Mechanical tests. Standard round specimens to be prepared from ingots deposited in a base-metal mould of such dimensions that normal cooling conditions will be approximated :

  (*a*) Tensile. To include yield-point, ultimate strength, total elongation, and reduction of area.
  (*b*) Bending.
  (c) Fatigue.

(3) Metallographic. Photomicrographs at 100 diameters.

Numerical Evaluation of Welds.—The evaluation of articles manufactured in quantity is usually determined by comparison with a standard of some kind. Where a number of variable properties or characteristics are involved, the most reliable evaluation is obtained by employing a numerical method. For example, each property is compared with the corresponding property of the standard and a percentage value assigned. Where such comparison cannot be made by actual measurement, a value is assigned which is based on judgment. If all of the properties are of equal importance, the final evaluation figure is simply the average of the various percentages. In general, however, certain properties are more important than others, and should therefore be weighted before averaging.

In the case of welds, most of the characteristics are determined by test and expressed in a numerical result. The standard is usually the base metal, so that an evaluation of each characteristic of the weld in per cent of that of the standard is easily made. The principal difficulty is in selecting the weights to be used when averaging for the purpose of assigning a value for the weld as a whole.

In the " shop standard " proposed, only one test is made so that evaluation is obtained directly. In the " commercial standard " three tests are made, the relative value of the results of which will depend upon the purpose of the investigation. If, for example, it is for the purpose of testing the applicability of welding to structures where the stresses are low but vibration is always present, the result of fatigue tests is of great importance. On the other hand, if the structure is a large tank for liquids, the fatigue test result is not as important as that of the tensile test and the bending test.

It is suggested that for general purposes the " commercial standard " be evaluated by weighting the tensile and fatigue tests by 1 and the bending test by 2.

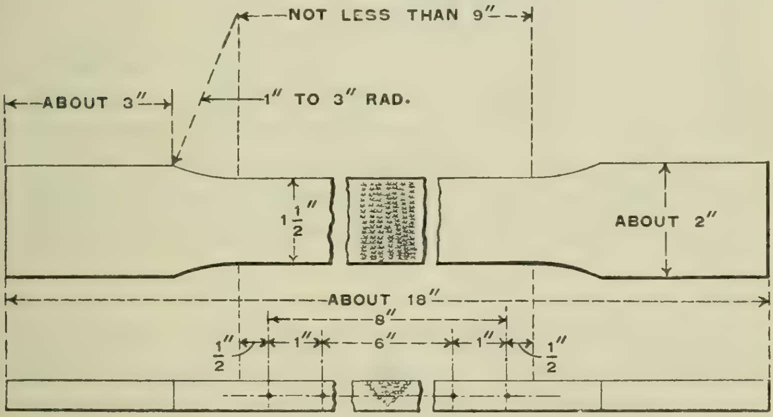
Standard Procedure in Mechanical Tests of Welds.

Of the three kinds of tests which are made for the purpose of investigating a weld, mechanical tests are the most important and are in the greatest need of standardization, because they yield information about those characteristics which are of greatest significance in the majority of applications of welding. Furthermore, they are the most easily made, are better understood by a larger proportion of those interested in welding, and the results are more readily interpreted.

There are five general classes of mechanical tests which may be made on ordinary structural materials — tensile, bending (transverse), torsion, impact, and fatigue. All five tests may be made on specimens cut from a sample weld, but tensile, bending, and fatigue tests will give ample data for all ordinary purposes. The impact test undoubtedly has much value in connexion with certain applications of welding, but it is questionable if a static torsion test develops any information that is not obtained from a tensile and a bending test. A standardized procedure is therefore particularly needed for tensile, bending, and fatigue tests. The procedures outlined in the following paragraphs have been used in a large amount of testing work and have been discussed to some extent for standards. It is believed by the Author that standardization along the general lines indicated will be in the right direction.

Tensile Tests.—Standardization along new lines should utilize existing standards as far as possible. The standard test specimen in America for rolled or sheet material is that of the American Society for Testing Materials, and is shown in Fig. 1. It has been suggested that tensile specimens from test welds* be of the same shape and dimensions.

Fig. 1.—*Standard Test Specimen in America for Rolled or Sheet Material.*



In some kinds of welding the test weld will not be flat, and in such cases the wide sides of tensile specimens should be at least rough-machined in order to insure parallel sides. In any case, excess metal at the weld should be removed, so that the cross-section area throughout the reduced section is constant

Gauge marks should be laid off along the centre lines of both edges 1 inch apart as shown in Fig. 1, the weld to be at the centre of the middle inch. The corresponding points on the edges should be in the same straight line perpendicular to the lengthwise axis of the specimen.

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* A term suggested for a sample or trial weld which is to be cut int specimens for testing purposes.

It is particularly necessary in testing weld specimens that the stress be applied in a straight line along the axis of the specimen, because any bending action due to non-alignment of the grips may affect the results, particularly if the weld is brittle. The rate of movement of the cross-head of the testing machine should not exceed that at which the beam can be kept accurately balanced at all times. The observations should include the load at the yield-point and at failure, the former to be taken by the " drop of the beam " method or with dividers.

The results should include the yield-point and ultimate strength expressed in lb. per square inch of the original area ; total elongation after rupture in 1 inch, 2 inches, and 8 inches expressed in per cent, each of the measured results as well as the average of corresponding results to be recorded ; contraction of area in per cent. The usual notes on the character of the fracture should be recorded, including comments on the extent of gas-pockets, slag inclusions, or incomplete fusion which may be shown.

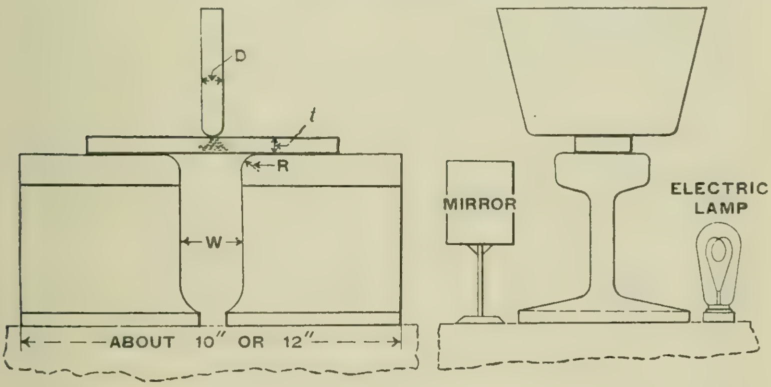
Bending Tests.—Of all the tests that are made on welds, none requires standardization more than the bending test, because it is of an arbitrary character, and there is therefore a wide divergence in the details of procedure. The result of a bending test is usually expressed as the angle through which the specimen can be bent when the first fracture appears, but this angle is obviously greatly affected by :

(*a*) the radius of curvature of the supports ;
(*b*) the shape and dimensions of the loading surface ;
(*c*) the distance between the supports ;
(*d*) the method used in measuring the angle.

Anyone who has made bending tests of welds will agree that all of these conditions influence the results, and where they differ it is impossible to make comparisons which have any value. Reference to results of tests of base or parent metal obtained with the same apparatus does not eliminate the difficulty, because many parent metals—mild steel, for example—will bend to the limit of 180 degrees over a wide range of the conditions enumerated above. It is, therefore, absolutely necessary to have a carefully standardized bending test procedure before bending tests of welds can be compared.

The bending test fixture shown diagrammatically in Fig. 2 has proved very satisfactory, and is one in which the features mentioned above can be readily standardized. It will be seen that the specimen is tested as a simple beam with a minimum distance between the supports and with the weld at the centre, the load being applied at the centre of the weld. Such an arrangement assures a severe test of the weld, because the joint is a maximum part of that portion of the specimen which is between the supports. The fixture is conveniently constructed if two pieces of steel-rail are used for the supports, with suitable provision for adjusting the spacing to accommodate various thicknesses of specimens. Fig. 3, Plate 13, is a photograph of such a fixture as used at the Bureau of Standards at Washington.

Fig. 2.—*Bending Test Fixture.*



The following are the essential dimensions :—

D = diameter of cylindrical loading surface = thickness of test specimen, t.

R = radius of corners of supports = 1 inch.

W = distance between supports = D + $2t$ + $\frac{1}{8}$ inch.

The top surfaces and corners of the supports are polished and lubricated with a heavy lubricant. In the case of a weld made with metal deposited in a " V," the specimen is always tested with the load applied to the side of the specimen which shows the least filled-in metal. The fixture can be conveniently used with a standard testing machine of the vertical type, but a simple, self-contained structure for applying the load can be readily constructed.

The quantity measured in the test is the *total* angle through which the specimen is bent at the instant the first crack appears in the specimen. As the test is usually made with the load applied in a vertical direction and on top of the specimen, it will be found convenient to view the under surface of the specimen by means of a mirror and an electric lamp suitably located as indicated in Fig. 2.

The angle of bend can be quickly measured by the simple method shown in Fig. 3, Plate 13. The outline of the upper edge of the specimen is marked on a sheet of paper held against the edge of the specimen (before the load is removed), and the angle measured with an ordinary protractor. As the specimen may not have been perfectly straight initially, a similar procedure should be followed before the load is applied. The difference between the two angles is the angle of bend which the specimen withstood, and is compared with the similar angle for a similar test of a specimen of the base metal. The width and length of the specimen may be any convenient values as far as the test itself is concerned. A width of 1·5 inch and a length of 6 inches have been found convenient for ordinary thicknesses of material. It is obvious that if the test is made with an ordinary testing-machine, the fibre stress can be calculated by the standard flexure formula for a simple beam supported at the ends and loaded at the centre.

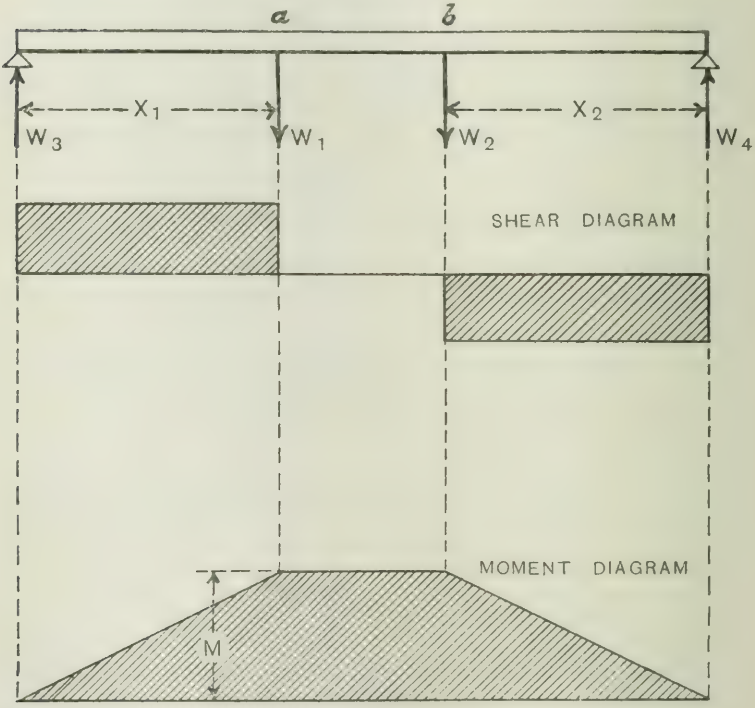
Fatigue Tests.—The fatigue test is of great importance in an investigation of welds, particularly those which are to be used in structures in which rapidly varying stresses exist, such as ship hulls, building structures, and machinery. It has long been recognized that the usual static tests do not necessarily furnish information from which the performance of a material under a long-continued variable stress can be predicted. It is desirable to know the effect of any type of joint in a structural member on the fatigue strength of that member. With a welded joint, the question becomes particularly important because of the introduction of more or less metal of a different character.

A fatigue test, like a bending test, is largely arbitrary. That is to say, the result obtained is an abstract one which has significance only when compared with other results obtained in exactly the same manner. In the case of tests of welds, the final answer is the ratio of the result of the test of a specimen containing the weld to that of a similar specimen of the base metal. Consequently, the exact method of procedure employed may not be as important as in the bending test, for example, provided the same test is made on both weld specimens and base-metal specimens. However, experience may show that this ratio is not reliable, for example, over a wide range of thicknesses of material, so that standardization of a fatigue test may be found to be necessary quite apart from the fact that it would be desirable on general grounds.

Many methods have been proposed for testing materials under varying stresses, and a number of machines have been developed commercially for making such tests of the usual structural materials, but the majority of these machines develop the maximum stress at a single cross-sectional plane of the specimen. A welded joint is not a homogeneous structure, for it not only consists of different materials, but in the case of a " V " weld, the area of cross-section of the filled-in metal varies throughout the joint because of the " V " shape of the filled-in metal and the irregularity of the line of union between the filled-in metal and the original metal. It is highly desirable, therefore, that the type of fatigue test employed for welds be one in which a uniform stress is developed throughout that part of the test specimen in which the weld is located.

A fatigue testing-machine in which this condition exists was developed for the Research Sub-Committee of the Welding Committee of the Emergency Fleet Corporation. It was described by the Author in a Paper recently presented before the American Society for Testing Materials.*

Fig. 4.



The principle employed is that of a four-point rotating beam with two free supports at the ends and two loads at the middle. Fig. 4 shows the familiar shear and moment diagrams for a beam so loaded, in which $W_1 = W_2 = W_3 = W_4 = W$ and $X_1 = X_2 = X$. The moment between *a* and *b* is uniform, and has the maximum value of WX. If the beam has a uniform circular section, the maximum fibre stress in all sections between *a* and *b* is

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* "A Fatigue Testing Machine." F. M. Farmer, Am. Soc. for Testing Materials, Annual Meeting, June 1919.

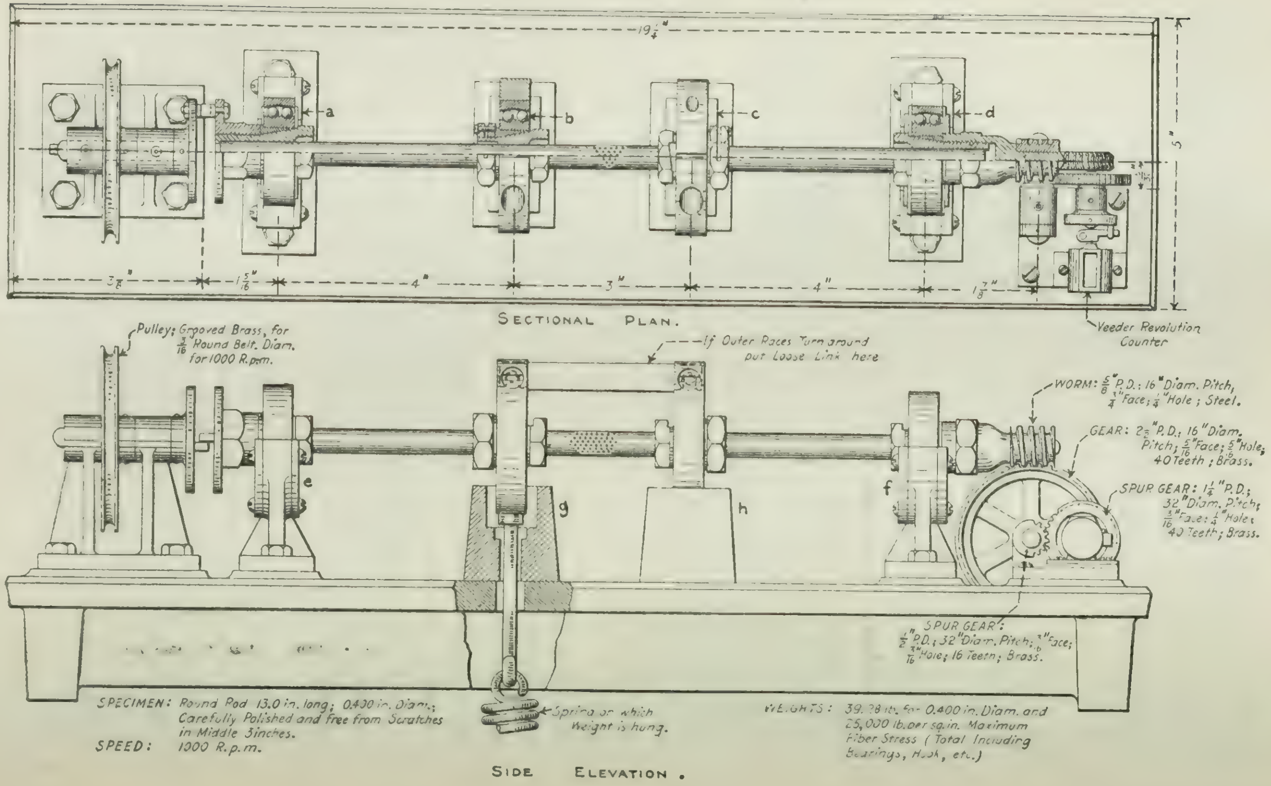
$$S = \frac{Mc}{I} = \frac{WX}{0 \cdot 0982\, d^3},$$

in which S = stress in outer fibre in pounds per square inch, M = bending moment in inch-pounds, *c* = distance from neutral axis to outer fibre in inches (= d/2), I = moment of inertia, W = load in pounds, X = distance between loads and supports in inches, and *d* = diameter of beam in inches. The beam is in tension on the lower side and in compression on the upper side. Thus if a circular rod is turned from a specimen cut from a weld, loaded in the manner indicated above with the joint in the middle and then rotated, the joint will be subjected to a maximum stress equal to S alternately in tension and compression once per revolution.

Fig. 5, Plate 13, is a photograph of a machine for specimens from welds in ½-inch material, and Fig. 6 (page 238) is a reproduction of a scale drawing. The specimen is carried by four self-aligning ball-bearings, *a*, *b*, *c* and *d*. The two end bearings rest in the pillow blocks, *e* and *f*, the whole being supported on a cast-iron base 5 inches by 19¼ inches. One of the pillow blocks provides for longitudinal movement of the bearing, due to the slight bending of the specimen. The two equal loads are hung from hooks attached to collars which encircle the outer races of the two middle bearings.

The bearings are securely fastened at the proper position by means of two split collets of carburized steel with opposite tapers, one entering from each side of the bearing. This produces a wedge action which gives a uniform pressure over the entire bearing surface on the shaft, and insures the validity of the assumption that the point of application of the loading forces is at the centre of the bearings. The inner collet is counterbored as shown, so that the bearing surface on the specimen is as short as possible. The collets are wedged together by a nut on a thread on the inner collet, and are loosened with the aid of a wedge-key driven under the head of the inner collet.

Fig. 6.—*Machine for Specimens from Welds in ½-inch Material.*


19¼"
5"
a
b
c
d
3⅞"
1 5/16"
4"
3"
4"
1⅞"
SECTIONAL PLAN.
Veeder Revolution Counter
Pulley; Grooved Brass, for 3/16" Round Belt. Diam. for 1000 R.p.m.
If Outer Races Turn around put Loose Link here
WORM: 5/8" P.D.; 16" Diam. Pitch, 3/4" Face; 1/4" Hole; Steel.
GEAR: 2½" P.D.; 16" Diam. Pitch; 5/16" Face; 5/16" Hole; 40 Teeth; Brass.
SPUR GEAR: 1¼" P.D.; 32" Diam. Pitch; 3/16" Face; 1/4" Hole; 40 Teeth; Brass.
e
f
g
h
SPUR GEAR: 1/2" P.D.; 32" Diam. Pitch; 3/16" Face; 3/16" Hole; 16 Teeth; Brass.
SPECIMEN: Round Rod 13.0 in. long; 0.400 in. Diam.; Carefully Polished and free from Scratches in Middle 3 inches.
SPEED: 1000 R.p.m.
Spring on which Weight is hung.
WEIGHTS: 39.28 lb. for 0.400 in. Diam. and 25,000 lb. per sq. in. Maximum Fiber Stress (Total Including Bearings, Hook, etc.)
SIDE ELEVATION.

The specimen is rotated through the loose coupling at one end of the specimen, and the revolutions are counted by a suitable counter geared to a worm on the other end of the specimen. These various fittings are most conveniently put in position on the specimen at a vice on a bench. The specimen with the fittings in position is then dropped in position in the machine, the weights hung on to the hooks (with spiral springs intervening), and it is ready to be rotated. The blocks *g* and *h* are merely for the purpose of preventing the weights from dropping too far when the specimen fails.

When failure occurs, the specimen will stop rotating because it "binds," and the belt will either slip or be thrown off. However, the preferable way for securing automatic stopping is to provide a simple switch arrangement which will be operated by one of the weights when it drops. This will cut off the motor.

This particular machine was designed for specimens from welds in $\frac{1}{2}$-inch plates, but obviously a machine could be constructed for specimens of any ordinary diameter. A machine could be constructed with a longer base for specimens from $\frac{3}{8}$-inch to 1-inch plate by providing bushings of suitable sizes and arranging for changing the distance between the supporting pillow blocks, so that the weight can be kept within reasonable limits.

The standard specimen for the machine described is 13 inches long and 0·4 inch in diameter throughout its entire length. This diameter is about the maximum that can be turned out of a specimen cut across a weld in $\frac{1}{2}$-inch material which is rarely perfectly straight. Care is taken that the diameter in the middle portion where the weld is located is exact, and that this part of the specimen is carefully finished free from tool-marks or scratches.

The criterion of the performance of a joint of any kind is the performance of a similar specimen of the original metal without a joint. Consequently fatigue tests of welds in $\frac{1}{2}$-inch plate are compared with tests made with the same apparatus and at the same stress on specimens from the original plate. When such tests were made with specimens of constant diameter throughout their length, failure always occurred at one of the load bearings and not between them, as is the case with weld specimens where the joint is usually the weakest part of the specimen. It is believed that this is due to the sudden change in the stress distribution, Fig. 4 (page 236), at these points, and probably also to the radial compressive stress induced at these points by the loads. By reducing the diameter between these points and using long fillets, failure will occur in the central portion of the specimen and the true endurance value of the metal will be obtained.

The objection might be made that the specimen is too small to give reliable information about what a weld of any considerable length would do, unless a number of specimens were cut along the weld. In other words, the machine should be such that it would take a comparatively wide specimen. The answer is that the very fact that the small specimens require a number of tests to be made is an advantage, because definite knowledge of the uniformity of the strength (or lack of it) along a long weld is very important, and obviously this would not be obtained with a single wide specimen. Furthermore, with the much greater speed permissible with a small machine and the larger number of machines which could be available, the equivalent in small specimens can be tested just as quickly as the one large specimen. Of course, a large machine employing the principle of uniform stress over the entire weld and which will take a long specimen is a great value in research work and has its place, but it is questionable if such a machine would be suitable or practicable as a standard for general use. A machine of this kind was designed by Professor H. F. Moore at the Bureau of Standards at Washington, D.C. It takes a flat specimen, 8 inches wide, 32 inches long, and of any thickness up to about 1 inch. The principle of the machine is exactly the same as that described above. The specimen is, of course, stationary, and the load is applied at the two loading points alternately up and down by means of an electric motor.

Number of Specimens that should be Tested.—A property which is most important in a weld is uniformity. It is therefore desirable to subject a number of specimens to each of the various mechanical tests. A separate sample or test weld can be prepared for each specimen, but in electric arc-welding in particular this means greatly increased expense in metal, in making the welds and in machine work involved in preparing the test specimens, because of the necessity for cutting away enough of the edges to eliminate the beginning and ending of the weld. In electric arc-welding at least it is more economical to make one large test weld, and cut it up into the pieces from which the test specimens are machined. In gas-welding a skilled workman may be capable of making a finished weld right up to the ends of the weld, in which case making each test specimen separately might be more economical. But the method of making one large weld has the further advantage that it duplicates more nearly the usual practical conditions, that is, long joints with the attendant temperature effects as determined by adjacent, relatively large masses of metal.

Not less than three specimens should be subjected to each of the mechanical tests. They should be cut from the test weld in such a manner that one specimen for each test is cut from the middle and one near each end, enough of the edges being first removed to eliminate defective welding which may exist at the beginning and end of a weld.

Elongation Data in Tensile Tests.—Elongation measurements on weld specimens are of limited value. The specimen is not homogeneous throughout its length, and unless the ductility of the filled-in metal of the joint is the same as that of the base metal, the result obtained is a composite of the ductility of the filled-in metal and the base metal. Such measurements have some value, however, when comparing welds of the same class with the same base metal. In a thorough investigation of a weld of the deposited-metal type, data on the ductility of the filled-in metal itself should be obtained by making tests of specimens consisting of filled-in metal only.

Width and Gauge Length in Tensile Tests.—The use of a specimen of constant width and gauge length, irrespective of thickness, might be questioned on the ground that it disregards Barba's law of proportionality, which states that the ratio of the gauge length to the square root of the area should be a constant. Investigations made by Professor H. F. Moore, under the auspices of the Committee on "Methods of Testing" of the American Society for Testing Materials,* showed that varying values of this ratio (within reasonable limits) do not affect the yield-point, elastic limit, reduction of area, or the tensile strength (of specimens of homogeneous material), but that there is a marked effect on the elongation.

So far as elongation data in tensile tests of welds are concerned, it has already been pointed out that such data are of limited value. This being the case, it does not appear that in ordinary tests of welds the additional complication involved in following standard dimensions based on Barba's law would be justified. But where investigations are being made to determine the effect of thickness on the weld, it may very well be advisable to follow this law. In that case it would appear desirable to make the gauge length as short as possible, and such that the ratio of the filled-in metal to the base metal within the gauge marks is a constant. Then the width should be varied to keep the ratio $\frac{L}{\sqrt{a}}$ a constant for the various thicknesses. For example, if test welds were made in various thicknesses of plate metal with a 90-degree angle in each case, and a specimen 1·5 inch wide with a 2-inch gauge length was prepared from the 0·5-inch material, the dimension of the other specimens would be as in the Table (page 243), $\frac{L}{\sqrt{a}}$ being constant at 2·31. Obviously, the tests of base metal which would be made for reference should be made on specimens of corresponding shape.

Standard Stress Value in Fatigue Tests.—In the fatigue tests made for the Research Committee of the Emergency Fleet Corporation, a standard maximum fibre stress of 25,000 lb. per sq. in. was employed in testing of weld specimens and the corresponding specimens of base metal. The selection of this value was based on the following considerations. The characteristic which it is desired to test is the elastic property under reversed stress conditions and not ductility, since in practice a material is never intentionally stressed above the elastic limit. This means, therefore, that the stress should be below the elastic limit, because the relative performance of materials in a fatigue test will probably be very different above the elastic limit where the property involved is ductility, than it will be below the elastic limit where elasticity is the property involved. On the other hand, the higher the stress, the more quickly results will be obtained. As there is no reason to suppose that the relative behaviour of different materials will not be the same at low stresses as at high stresses (provided they are below the elastic limit), a stress of 25,000 lb. was adopted. This is as close to the elastic limit of ship-plate steel as it was thought advisable to go.

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* Proceedings, Am. Soc. for Testing Materials, vol. xviii, Part I, page 399 (1918).

Thickness.	Width.	Gauge Length.
Inch.	Inches.	Inches.
0·125	0·375	0·50
0·25	0·75	1·00
0·50	1·50	2·00
0·75	2·25	3·00
1·00	3·00	4·00

In an extensive research investigation, it might be advisable to determine the stress at which failure occurs after a stated number of reversals (or repetitions) of stress by the application of Basquin's exponential law,* $S = \frac{K}{N^r}$, where S = fibre stress, N = number of repetitions of stress at failure, and K and x are experimentally determined constants. Tests would be made at a number of different stresses below the elastic limit and the results plotted on logarithmic paper. According to this law the curve should be a straight line, so that the stress which will cause failure at any particular number of repetitions of stress is readily determined.

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* O. H. Basquin. "The Exponential Law of Endurance Tests." Proceedings, Am. Soc. for Testing Materials, vol. x, page 625 (1910).

This method gives a more fundamental basis of comparison. It permits direct comparison of the fatigue strength of different kinds of welds and welds in different materials without reference to the fatigue strength of the base metal. It is obvious, however, that the various specimens must be very uniform if reliable information is to be obtained with a reasonable number of tests.

Inspection and Tests of Welds in Structures.—The phase of the welding art which is in greatest need of standardization is that of inspection and testing of completed welds in commercial applications. But progress towards this desirable end can hardly be expected before a satisfactory and commercially practicable method of determining the quality of a weld in a structure is devised. Investigations of various suggested methods of testing completed welds were made by the Welding Committee of the Emergency Fleet Corporation. These included X-ray examination, determination of the electrical resistance by a method somewhat similar to that employed in testing rail-joints in electric railways, hammering and chipping of the weld and magnetic examination. None of these offered definite promise of success at the termination of the Committee's activities. In certain limited fields of application, satisfactory tests may be devised, such, for example, as closed vessels which can be subjected to hydraulic pressure and simultaneous hammering after completion. Possibly also some method will be devised for removing a test-specimen which can be readily tested, the hole being small enough to be filled up easily.

But at the present time the only checks on the quality of the welder's work in general applications which are available appear to be (*a*) confidence in the welder's proficiency and his integrity, and (*b*) systematic inspection *during* the progress of the work. Even here standardization may be applied advantageously. That is, we should have (*a*) a standardized test of proficiency of welders or perhaps several standards for different grades of welders and (*b*) a standardized procedure for the inspection of various kinds of welds while being made. Standardization of this kind should have the added value of aiding in obtaining the confidence of those authorities whose approval is necessary before welding can be applied in a number of important fields.

The Paper is illustrated by Plate 13 and 4 Figs. in the letterpress.

Discussion in London, on Friday, 18*th February* 1921.

Mr. WILLIAM H. PATCHELL, Vice-President, in the absence of the Author, presented the Paper. He said his only qualification for doing so was that he had had the pleasure of discussing it with his friend, Mr. Farmer, in New York last year. Mr. Farmer was connected with a large and distinguished Institution in New York and with the American Bureau of Welding.

The PRESIDENT proposed that a hearty vote of thanks be sent to the Author in New York and should also be accorded to Mr. Patchell for having at the last moment undertaken to present the Paper. The establishment of standard tests of welds was important and difficult, and it was due to the want of such tests that electric welding and other kinds of autogenous welding were not used as much as they might be.

Brig.-General R. K. BAGNALL-WILD, C.M.G., C.B.E., said the Author was a brave man to tackle the subject of inspection of welds. This had, so far as he was aware, never been thoroughly discussed in England, and he hoped that the discussion would be of value in ventilating the subject. He would confine his remarks to commercial testing only, testing under bulk production, and to the use of welded

(Brig.-Gen. R. K. Bagnall-Wild.)

thin sheet, tubes and metal fittings for aircraft. In reading through the Paper he had been struck by the fact that the tests to be imposed were tests of special pieces, in other words, the testing of the ability of the workman who was going to put his very best work into the test-pieces and not the testing of the welds under ordinary commercial production. It might be asked how could that be done, and, as a matter of fact, he was bound to say he did not know. In aircraft work, welds were not used where the part was subject to direct tensile stress or to shear. The only useful method of testing he had discovered was to test the actual part, that was, to select and destroy a certain percentage of finished articles and make a test-piece cut therefrom.

In the material tests he noted the composition was given, and he regarded that as of great importance, but would suggest that the percentage of nickel should be specified in the composition. He had had experience of failure with some sheet steel. It would not weld. It was ordered as an ordinary carbon-steel, but it was found eventually that the scrap used in making that steel contained a percentage of nickel. Nickel had to be down to practically 0 per cent or, at the worst, only a trace. With regard to the mechanical test, he noticed that the Author did not say whether his test-piece was tested as cast, that is, as welded, or whether it was subsequently normalized. That was most important, and should be stated in the specification. He himself would prefer it to be normalized.

Then again, the Author machined his weld. So far as thin material was concerned, it was quite impossible to get any test result representing the finished article if the skin was machined off. The bending test was a good one and he himself had used it right throughout the War. The stress-reversals test, he suggested, was hardly a commercial one ; it was very useful, but he would substitute for it an ordinary impact test in commercial testing. With regard to the Author's reference to the angle of the V, that ought to be most carefully considered when tests were being made, and should be recorded every time.

To guarantee safety, so far as possible, the selective scheme was essential, that is, destroying one part in a certain percentage according to the importance of the finished article. A most useful test was to saw the part up longitudinally, etch it with picric or nitric acid, and examine the surface. That was especially necessary, not so much with regard to the material in the weld itself but with regard to what had happened to the material in the neighbourhood of the weld.

Mr. R. S. Johnson (Lloyd's Register of Shipping) said that the first case of any repairs to vessels classed with Lloyd's Register being effected by welding occurred in 1906, although the practicability of welding by the electric arc process had been demonstrated many years before that time. The satisfactory nature of these early repair jobs had led to the permanent establishment of the art of welding in the engineering world, and its field of application was rapidly extending with the increase of knowledge and experience of the subject. In 1917 welding was in a sufficiently advanced stage to warrant the possibility of its being applied to the structural members of a vessel, and it was realized by Lloyd's Register that more information should be obtained regarding the physical properties of welding and welding material, before the introduction of welding in place of riveted work, in a structure subject to alternating stresses, could be approved. Experiments for the purpose of ascertaining the ultimate strength of welded connexions had already been carried out at Washington and by the British Admiralty, with very satisfactory results, but they were quite inadequate so far as a general standardization of welding tests was concerned.

The tests arranged and carried out by Lloyd's Register were very similar to those recommended by Mr. Farmer, and they had been fully described by Sir Westcott Abell, K.B.E., in his Papers read before the Institution of Civil Engineers and the North-East Coast Institution of Engineers and Shipbuilders. So far as mechanical tests were concerned, the only practical import they held for the structural engineer was the evidence they gave of the properties possessed by the welded joint when stressed up to the elastic limit, or it would perhaps be more accurate to say, within the working limits of the material used. Ultimate strength was only of value as a rough test, while the measurement of the yield-point and of the

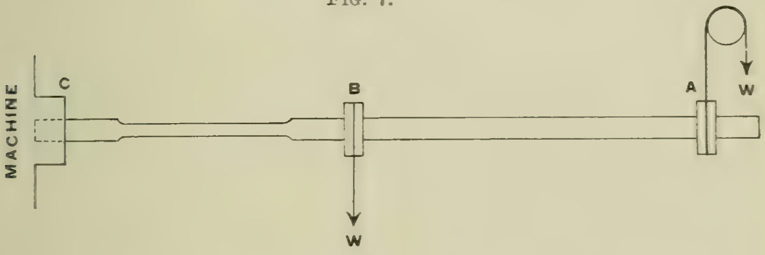
(Mr. R. S. Johnson.)

total elongation was entirely misleading, because of the fact that the weld formed such a small portion of the length of the specimen over which these items were measured. The ultimate elongation of a welded specimen was considerably less than that of the unwelded plate, and the reason for this was that at high stresses (exceeding the elastic limit) the welded material was much less ductile than ordinary mild steel and broke abruptly, without flow of the metal and without a gradual contraction of area at the point of fracture.

In the experiments carried out by Lloyd's Register, the average ultimate elongation measured over a distance of 8 inches was found in the case of a plain piece to be 29 per cent, for a longitudinal weld 12 per cent, and for a transverse weld 8 per cent. The measurement of the reduction in area at the point of fracture had no practical value, because in most standard systems of welding it was found that the test-piece broke clear of the weld. The Author attached considerable importance to the value of the bending test. In the tentative regulations and tests required by Lloyd's Register for the approval of welding systems, no bending test was included, and this was in view of the results obtained from a series of cold-bending experiments. The specimens were 18 inches in length by 3 inches in breadth, and were bent over a block having a diameter equal to three times the thickness of the plate. Tests were made with plates ranging from $\frac{1}{4}$ inch to 1 inch in thickness and with the apex and the base of the weld arranged alternately uppermost. As was expected, there was considerable difference in the angle of bend in the two cases at which the specimens fractured, depending upon which end of the weld was uppermost. In the $\frac{1}{4}$ inch and 1 inch plates, the average differences in the angle of bend were found to be 14° and 5° respectively. The best angle of bend at which fracture occurred in the $\frac{1}{4}$ inch plates was 87° and for the 1 inch plate $23\frac{1}{2}$°, whereas similar test-pieces of plain plate cut from the plates from which the welded samples were made were found in all cases to submit to an angle of bend of 180° without fracture. It would, therefore, be unreasonable to include a bending test in any regulations framed for the purpose of testing the merits of a system of welding. It could also be concluded from the results of these bending tests that the angle at which the V was cut in the original plate, would have considerable effect upon the angle of bend at which fracture would occur.

The Author stated that in structures where vibration was always present, fatigue tests were of great importance ; especially was this so from a shipbuilder's point of view ; but for general purposes, giving due consideration to the experience gained of bending tests, it would be more reasonable under his system of numerical evaluation to assign a value of 2 to the fatigue tests and certainly not more than 1 to a bending test. In such a structure as a ship, it was of extreme importance that welded joints should be able to withstand continued alternating stresses, and a series of rotary tests were for this reason required by the Rules of Lloyd's Register. The tests were similar to those recommended in the Paper, but Mr. Farmer's machine appeared to be unnecessarily heavy and complicated. The machine devised by the staff of Lloyd's Register for this purpose was in accordance with the suggestions of Dr. W. Mason, A.M.I.Mech.E., of the University of Liverpool, and was shown diagrammatically in Fig. 7.

FIG. 7.



The specimen is held in the grip of the lathe at C and is loaded with equal weights of known amount at A and B, at which points the rod is carried in ball-bearings. This arrangement of loading produced a uniform bending moment over that part of the rod between B and C, and the weights W being known, the stress on the material of the rods could be easily calculated. The specimen was

(Mr. R. S. Johnson.)

reduced in diameter in the region of the weld to ensure fracture taking place clear of the points of support. As the rod was revolved, the stress on each part of the material changed during each revolution from compression to an equal stress in tension. The total cost of the machine was about £90, so that the expense occurred in adding such a machine to a welding equipment was not of great consideration. The shearing force diagram shown in Fig. 4 (page 236) had no value, as in these rotary tests the failure of the specimen was not due to shear.

A further test, not included in the Paper but required by Lloyd's Regulations, was one of impact. It was found that in some early cases of welding when the run was struck by a hammer, pieces of the welding material became loose, and in testing a system it was therefore considered advisable to include some test that would give an indication of the brittleness of the weld. It was found that welded plates could withstand impact with a considerable degree of success ; a $\frac{1}{2}$-inch plate arranged on supports 4 feet 6 inches apart and raised 18 inches from the ground sustained two successive blows of 4 cwt. dropped through 12 feet, giving a deflection of 12 inches without any signs of fracture in the weld ; and in no case had any failure occurred under this test.

Since the completion of the tests of 1918, the Committee of Lloyd's Register had continued their researches into the question of electric welding and for their information Dr. Marchant, of Liverpool University, had carried out a most exhaustive series of experiments with a view to ascertaining the electrical conditions under which welding should be carried out and, if possible, to determine the electrical properties of the electrode. An automatic welding machine was devised to enable the welding to be carried out in a perfectly definite way to secure comparable results in respect of variations in current and voltage. Various types of electrodes were used, and by means of an oscillograph, photographic records were obtained showing the variation in voltage and amperage during the process of welding. From the results obtained, it would appear that the current and pressure were much steadier when the electrode was positive than when it was negative, but there was not sufficient difference to justify the use of such a method as a means of comparing electrode qualities, nor did it appear that the electrical conditions in the circuit during the process of welding could be used as a criterion of the soundness of the welded joint.

A second series of experiments had the object of finding out whether the method of controlling the current used for the arc had any effect on the quality of the welded material. Two pairs of plates were welded by hand, the current in one case being controlled entirely by resistance, and in the other case largely by reactance. The result of fatigue and tensile tests carried out on these specimens showed that the fatigue strength and character of the metal deposited at the welded joint were not seriously affected by the nature of the current and pressure regulating arrangements. Dr. Marchant also devoted much time to the development of the design of an apparatus which would enable faulty places in a weld to be detected, and had constructed a tester which might be useful for determining faults in a weld or cracks in a flat plate.

Mr. E. R. DOLBY said he wished to offer two or three words of reminiscence and to ask a question. He was driving along the Embankment in a hansom cab one day and saw the roof of Charing Cross station suddenly fall in; there were not many people, he thought, who saw that accident. The result, as probably a great many members knew, was due to the breaking of the welded joint of a tie-rod. A short time ago he had the interesting experience of seeing some sections cut through the defective welded portion of that very tie-rod; it was about 4½ inches in diameter and there was a hole as large as a hen's egg right through the welded section. When reading the Paper the question arose in his mind: Would any process have discovered the defect in that tie-rod at the time, or shortly after, it was made? He could see no prospect, from what had been said in the Paper, of any test being made that would have proved the unsoundness of that rod.

Captain DAVID RICHARDSON, R.A.F., said it would probably be of interest to the members to know what had previously been done

(Capt. David Richardson, R.A.F.)

in the way of standardization in the testing of welds. At the Congrès International des Méthodes d'Essais, held at Zurich in 1895, a method of verifying the quality of welds was proposed. In 1912 the Bureau Central de l'Acetylene and Soudure Autogène of Nuremberg offered a prize of 1,500 marks for the best solution of the following question: "In what manner may the presence of oxide inclusions, unwelded portions, and the burning of the metal be discovered in an autogenous weld without damaging the line of welding?" There were twenty-six entries, none of which were satisfactory, and of which five gave possible lines of development. The application of electrical and magnetic methods had proved to possess serious difficulties. The electrical resistance method of determining the presence of cracks was dealt with in an article in the *Revue de Métallurgie* of January 1913. At the present time the Office Central de l'Acetylene of France were engaged in a series of official tests for establishing methods of testing welds.

With regard to the Paper, it was interesting to note that the American Bureau of Welding was a product of the War, and practically the whole of the programme, of which the Paper represented one item, was only fixed at the latter end of 1920. The Emergency Fleet Corporation formed a Welding Committee, which comprised representatives from England. With the close of the War, when the Government withdrew from the activities created by it, the American Welding Society was formed to carry on the work. From this emerged the American Bureau of Welding, the functions of which were to establish and standardize the facts, to conduct researches and to furnish a sound basis for an industry which was bound to become of the first magnitude. The standardization of testing welds was only one of the items in the programme. He was of the opinion that some of the other items were much more important at the present time, for instance, the standardization of welders and equipment. The necessity for elaborate tests which, in many cases, were of little real value, would disappear with well trained and conscientious welders. The practical test of a weld was the character and training of the man who made it.

The value of tests on welds was often negatived by the procedure followed. A specimen weld was generally taken machined or turned up, thus frequently eliminating one of the most serious defects of welds, namely, lack of penetration. With reference to the bending test, he had found that this test was of great value in training welders, but the bending was not applied as shown in the diagram. The question of preliminary tests on the materials, which in the case of oxy-acetylene welding would include a blow-pipe test, was very important. In view of the enormous value of examining welds in situ, he forecasted that the development of X-ray examination would lead to its establishment as one of the chief, if not the chief, method of examining and testing welds. He had found that simple etching tests were of great value.

Dr. B. P. **Haigh** agreed that it was most desirable that some method should be found for testing finished welds in structures; but as no convenient method was at present available for this purpose, it was necessary to rely on tests on special samples. As the Author had stated, much depended on the proficiency and integrity of the individual welder. He thought that only two sets of standards were really important, namely, (1) Shop-tests to ascertain when a welder had attained a reasonable standard of proficiency, and (2) a series of Standard tests for specifications. He did not doubt that research would continue to look after itself in the matter of standards.

The tensile test could no longer be regarded as a sufficient criterion of strength, particularly when the results were given as percentages of the strength of the plates. Having had an opportunity of testing a series of twenty welds produced by the Kjellberg process, he had found that not one of these broke through or near the weld.

With regard to fatigue tests, which the Author wisely recommended for specification purposes, he did not think the type of machine described in the Paper was the most suitable. In any rotating-beam test, the results depended unduly on the metal at the outside. Whereas a test-piece with a large flaw near the centre might give good results in such a test, the presence of only a slight

(Dr. B. P. Haigh.)

flaw near the outside would give a poor test result. It was greatly to be preferred that the stress should be uniformly distributed across the full section, as well as along a considerable length. He had obtained very successful results with a machine that fulfilled these requirements and worked, moreover, with a much higher frequency of reversal, thereby reducing the time required for the completion of a test. He deprecated the Author's statement that fatigue tests were necessarily arbitrary; the limiting fatigue stress could be measured with very great accuracy in a suitable machine. The figure suggested by the Author as a standard fatigue strength appeared to be suitably chosen. In a series of tests on Kjellberg welds, more than half the number of test-pieces had withstood over five million reversals with stresses over 10 tons per square inch.

Although the Author had mentioned the impact test among the headings under commercial tests, no standards had been suggested. As the impact test often revealed brittleness in welds that gave good results in other respects, that omission was an important one. The Izod test was a simple and practical one, and deserved careful consideration for welding work. It could be recommended as a shop test, and appeared preferable, for this purpose, to the bending test described by the Author. The Izod test always broke the test-piece, so that the fracture could be examined: a matter of great importance since the characteristic appearances of tough and brittle metal were now well known. Another excellent shop test was the torsion test, carried out by twisting a sample composed wholly of added metal. By measuring the number of turns obtained on, say, 100 diameters, and observing the uniformity of twist along the length, it was possible to form a very reliable opinion of the degree of proficiency attained by any individual welder, working under specified conditions, as in "overhead" work. It was not unreasonable to expect thirty complete turns on a length of 100 diameters.

For photomicrographs, a magnification of 100 diameters was not the most instructive for studying welds, although it was suitable for general purposes. At this magnification, all welds appeared more or less alike, and the characteristic features that made for toughness or brittleness were not clearly indicated. Figs. 8–12, Plate 14, illustrated this point. In Fig. 8, which showed the junction between the original plate and the added metal in a V butt weld, a magnification of 100 diameters illustrated the brittle structure produced by overheating the plate, but did not show the characteristics of the added metal. The effects on the plate were more clearly shown in Fig. 9 with only two magnifications. This showed the same V butt weld, which had been produced by adding metal in three distinct runs. The bottom of the V was not completely filled, as the electrode had been somewhat too thick for the purpose. The first run of added metal comprised two distinct layers, although the profile showed clearly that they had been added simultaneously. The lower part had a coarse brittle structure, while the upper part had been refined by the heat of the second run. The second run had likewise been refined by the heat of the third ; while the third retained its coarse original structure. Thus the interior of the weld was tougher than the exterior. The same view showed very clearly how successive waves of heat had traversed the metal of the plates, embrittling them in a narrow zone and refining them in wider zones. He thought such low-power views were of great value for research and for other purposes.

Fig. 10 showed a face view of a tensile fracture and served only to elucidate the contrast between two subsequent figures. The fracture showed that part of a particular weld was tough, and part brittle. That was a not uncommon state of affairs, particularly when the welder was none too proficient. At 500 magnifications, as used for Figs. 11–12, the cause of this difference was clearly revealed. The tougher part showed the characteristic Ferritic structure with finely divided carbonaceous particles, while the brittle part showed a laminated structure that facilitated the development of cracks.

Dr. T. E. STANTON, C.B.E., Member of Council, said he quite agreed with the other speakers who insisted on the value of the impact test. In a weld the heat treatment of the metal was very severe, and he thought there might often be set up in the neighbourhood of the

(Dr. T. E. Stanton.)

weld a form of brittleness which could not be detected by any other mechanical test but the impact test. He also agreed with the speaker who said that the standardization of the welder was equally necessary. If it were possible to get some sort of examination which a welder could undergo, it would be a very good thing. He believed that, during the War, ex-Service men were taken, who had had no training, and in six weeks were turned into efficient welders. In South Wales the other day he had seen, in welding gas-cylinders for high pressures, that every welder had his own little stamp, and when he made a weld he stamped it so that it might be identified, and this practice, he thought, might also be adopted.

The PRESIDENT thought that Dr. Stanton's view was to test the welder and not the weld.

Major J. CALDWELL said the Author had referred to the absence of welding standards of any kind in America. Although comprehensive welding tests had been undertaken in the United States, they were invariably carried out by welding enthusiasts, or on behalf of large users or prospective users of the process. The result of the former were not suitable for intelligent comparison of materials and workmanship, whilst for obvious reasons the latter had to be considered confidential and withheld from competitive parties interested in the manufacture and supply of the electric welding material and apparatus used. During the War many of the latter tests were communicated to this country, and he was glad to have the opportunity of acknowledging the useful purpose of certain unbiased and careful investigations carried out on behalf of his Company by Mr. E. B. Katte, Chief Engineer of the New York Central Railroad Company. The Wirt Jones tests represented an attempt at standardization on the part of the Welding Committee of the Emergency Fleet Corporation of the United States Shipping Board, but those tests were not convincing, because no attempt was made to standardize the operation and the method of executing the work. He was justified in making those remarks because he was one of the original members, and represented the Admiralty on the

American Welding Committee. In this country we had been more fortunate in standardizing tests of welded joints. The testing of electric welds had engaged the practical attention of the Admiralty and Lloyd's Register of Shipping during the last three years, with special reference to shipbuilding use. Both those bodies had found no difficulty in adapting to welds the methods which they had developed during many years for testing materials and the reliability of workmanship in shipbuilding.

It was doubtful whether there was any great advantage to be gained by standardizing the size of test-pieces. The size necessary to test a weld under conditions approximate to those in use might vary very considerably. For example, for butt or lap welds in ship plates or similar structures, it was more representative to use a large width of plate than to cut out a narrow specimen which might or might not be fairly representative of the whole weld. Lloyd's tests included specimens 20 inches and 48 inches wide, and clearly a riveted test-piece of 1½ inch or 2 inches would not give the true strength of riveted joints.

The Author advocated a bending test, which was a most searching and simple test for workshop use. It was the readiest way of testing the quality of a welder's work, different kinds of electrodes, and other changes in working conditions. The question of the cylindrical loading surface to be used for bending tests came into consideration. The Admiralty used a block with a radius of 1 inch for ¼ inch plates, and 2 inches for ½ inch up to 1-inch plates; Lloyd's required a block having a diameter equal to three times the thickness of the plate; whilst in another series of tests carried out by the National Physical Laboratory the block radius was slightly less than the thickness of the plate. He certainly thought the block radius should be somewhat more than the thickness of the plate. It was very doubtful whether the bending test was of any real use for commercial testing. Members of structures were not as a rule exposed to large angles of bend in use, and in designing them, joints of any kind were so placed that they were not subjected to such bends. Reverting to workshop tests, he would like to suggest that for training welders and testing the suitability of electrodes, the microscope should have an important

(Major J. Caldwell.)

place. He was strongly of opinion that all the photomicrographs that were shown for comparative purposes should be of about 1,000 magnification, and they should be shown frequently to workmen, because they were more convincing than anything as to the class of work that was turned out.

He wished particularly to emphasize the importance of practical tests. The stresses on structures were often composite, not predictable, and not to be produced by testing machines. Electric welding had already made good in this country for such diverse uses as shipbuilding, large tank construction, steel buildings and roof trusses, and had been used for these services to a much larger extent than was realized ; the process also had been used recently in the manufacture of wheels for motor-omnibuses and large commercial vehicles. The last use was emphatically of the most searching kind. The stresses in a motor-omnibus wheel were composite, alternating, tensile, compressive, bending and torsional, combined in unforeseeable ways. Electric arc welding had given excellent results after extensive use, and such built-up wheels, each comprising ninety-three welded parts, had given many thousands of miles' good service on the London streets, with no sign of failure.

Mr. WILLIAM MILLS said the way he tested blacksmiths' welds was to let the weld cool down and re-heat it ; if it was a bad weld, a dark mark would be seen and the weld would be condemned. When it was broken, it would always be found to be a bad weld. He had never known a weld inspected in that way that gave out afterwards. This method was well worthy of some further research, and had a value, because the weld was tested without being broken.

With regard to the Charing Cross station tie-rod, which had been mentioned by Mr. Dolby, he thought that, if it had been re-heated where the weld was made, a different colour or transparency would have been seen and the flaw detected. That method had been used with entire success in his works for thirty or thirty-five years.

Mr. WILLIAM H. PATCHELL, on the Author's behalf, thanked the

Meeting for the manner in which the Paper had been received. His own experience of welding had been in connexion chiefly with steam-pipes, with which he had experienced no trouble since the first lot he tried in 1895, quite early in the art. He believed the Admiralty would not use a welded steam-pipe flange. Why, he did not know. He thought if it was possible to get some standard of test for welds, the Admiralty as well as other people would be convinced. When the Paper was first offered to the Institution, he tried to get a Paper read by an Englishman to read with it, thinking that the standard methods on this side of the Atlantic and on the other side might be compared, but on going into the matter he found there was no accepted standard method. He believed there would be no difficulty in getting specimens, which would cost the contributors practically nothing, and yet in the aggregate would be of very great value, and the work of testing those specimens could be done by people who had testing machines and methods of testing. The result would be of great importance. He thought the Institution or the Iron and Steel Institute should take the matter up, as it would be probably better work for them than for the British Engineering Standards Association. In spite of the suggestion that had been made by one speaker, that the Americans were trying to put it on to Great Britain to carry on with the work, he thought they were trying to do their best, and if this country also did its best some useful results would be obtained.

Discussion in Manchester, on Thursday, 24th February 1921.

Mr. FARMER's Paper was presented in abstract to the Meeting by Mr. WILLIAM H. PATCHELL, Vice-President.

The CHAIRMAN (Mr. Daniel Adamson, Member of Council), said it seemed to him the Paper emphasized the necessity of giving consideration to the subject from the metallurgical point of view. To many of them it was not easy to appreciate photomicrographs,

(Mr. Daniel Adamson.)

and they could not have Papers of this type put before them too often, because every time they learned a little, until at last they were able to obtain safe and practical guidance for their work. Care must, however, be taken in the design of the objects to which the process was to be applied, and particularly in the location of the welds. As had been pointed out many times, welded seams were not suitable to resist bending action. In recent years they had flanged the ends deeply and so placed the weld farther away from the place where the tendency to bending was felt.

A simple test, which had not been alluded to in the Paper, but which was applied in his own workshop, was known as the hot-forge test. A small piece of plate was cut and welded across the centre, and then pressed or forged out to various shapes. They were thus able to test under similar conditions according to the various methods of welding, electric, gas, coke-fired, and ascertain their suitability. In many instances plates had to be joined together because they could not get plates sufficiently large for the purpose in view for the end of a vessel; therefore they were always on the look-out for some means of uniting two pieces to form a homogeneous plate, so that they might afterwards be flanged into the shape required. Very often electric welding was resorted to in order to remedy the results of corrosion. Difficulty was caused by the varying electrolytic qualities of the two metals, the added material differing from the original material, and corrosion was accentuated. In some instances, trouble arose through the use of welding as a last resort to get out of an awkward position, due to the faulty design of the vessel.

The Papers written on this subject generally arrived at the conclusion, which was well put by the Author at the close of the Paper now under consideration, that one must have confidence in the welder's proficiency and his integrity. The way to ensure it was by some systematic way of making tests of the work of the operator, so that he would acquire confidence in his work and at the same time instil into the responsible authorities that confidence which was necessary before welding was applied in more important fields of industry.

Mr. C. E. STROMEYER asked which part corroded more rapidly—the weld itself or the plate adjoining the weld?

The CHAIRMAN said it was the original plate rather than the added material of the weld.

Mr. S. BOSWELL said the Paper opened up a question which had not yet been grappled with, namely, boiler repairs. These were chiefly in his mind when he considered the questions of corrosion, grooving, and fractures. An electric welding plant could not be placed in the hands of a working boiler-maker, nor could electric welders be mixed up with the other men in a boiler shop. Here came in what seemed to him a very great inconsistency on the part of the various inspecting offices. In any new structure which had to carry pressure, they would not allow the slightest trace of local heating. But when it came to electric welding, they got local heating intensified, and electric welding was generally required at that part which felt the strain. This strain could not be measured, but it was known to be present.

Mention had been made by the Chairman of corrosion being seen along the edges of the electric weld and occasionally on the weld metal itself. This was evidence of the work having been done by a handy labourer welder who had not the slightest knowledge of metallurgy, nor yet as to what he was using. The consequence was he soldered the thing together, and when that failed and the boiler-maker came to do the job, they found trouble. Sometimes the metal was so hard that a chisel would not touch it.

For other than pressure purposes, electric welding was no doubt quite the thing, but in his opinion it was not in a satisfactory state to lay before the public for making anything which was to go under internal pressure. For instance, one found leaky seams which might be due to a defect in the structure or to some fault in the handling of the boiler. The so-called electric welder came and simply sealed up the seam. In a very short time it broke through again, but the whole thing was now welded in one solid mass and the two plates could not be separated again when the renewal of the parts was necessary, due to the defective weld.

(Mr. S. Boswell.)

It was known that they must have a raw metal surface to work on, but some of the younger men did not consider that. The consequence was, they thought nothing of filling up the groove, with the result that after the boiler had been working two or three weeks, the filling came out again. As an expedient to keep a steam-boiler going until proper material could be prepared, electric welding might be and was being done by an expert, but it was not a permanent repair where riveted seams were in the area. He would be very glad indeed if he could feel satisfied that the electric weld for all-round boiler repairs was a success, but he had not yet found it so—for instance, down the narrows in a boiler on the water side where they had 4 inches to work in. Some people were foolish enough to think they could do it in the space of 4 inches when a man could not even see the defective part, or what he was doing, but had simply to feel his way.

With regard to corrosion, he said that some years ago he made a study of corrosion. In one case on the water side, he found the corrosion following the line of flame and hottest gases rising over the bridge, and gradually dying off as it got away from the firing end. In another boiler, the colder portions were similarly affected and the hotter portions were not. They used the same feed-water, but there was that difference, no doubt due to the character of the metal.

One place where corrosion could very often be found in a boiler was in front of the mud-hole. In the seating of the boiler was always a spot in which the deposit accumulated. Sometimes the pitting was allowed to go too long, and then a hole had to be drilled through the pitting and a rivet put in. But if it were properly cleaned, the pitting could be filled up to the original thickness by welding. As regards the testing, he failed to see how an efficient test could be made that would be of use in boiler repairs. A boiler in use was a living thing, continuously breathing and changing its conditions to meet the varying conditions of heat pressure or tension thousands of times per day. His remarks on welding had reference to pressure boilers only.

Mr. C. E. STROMEYER, O.B.E., observed that the welds being occasionally very hard might be explained by what happened in connexion with one of the specimens in the Museum of the Manchester Steam Users' Association. A firm of welders suggested that some leakages of the tube-ends in a locomotive boiler could be repaired by having the circumferences welded. In order to show that this could be done, a sample tube-plate and tubes were prepared and the tube-ends welded. On trying to saw through them, narrow zones of very hard metal were met. This was due to having accidentally used a piece of hard steel for the tube-plate, the molten steel becoming hardened by contact with the body of the plate, which was relatively cold.

One trouble about welds was due, he believed, to patentees who could find no better protection than by attaching superlative importance to the quality and amount of their special flux, which, unfortunately for practice, unless it was carefully pushed away by the welder, left a number of cavities in the weld. Some welders merely used a thin coat of some sort of whitewash and obtained excellent results.

His own position with regard to welds was that engineers did not as yet know much about them. The Manchester Steam Users' Association had asked its inspectors to take special notice of anything peculiar about electric welds of old standing; perhaps in a year or two they might get information for and against welds, but as yet they did not know whether electric welds were as good as they professed to be or not. Certainly there had been cases of plates cracking which had been welded, and if that was due to the weld it was, of course, a serious matter; but if it was due to the material used, or to the material of which the boiler was made, the matter was not so serious, because they might then get over the difficulty by using good welding material or refusing to weld plates which were unsuitable. He had heard from one welder that he would not weld a boiler which was more than twenty years old, but as a matter of fact that same welder had welded old boilers which would now have to be watched. There seemed to be indications that even the best Low Moor Iron deteriorated as it got old. He did not feel

(Mr. C. E. Stromeyer.)

quite sure on that point, but if it could be shown that some change which took place in the material affected the welding, there would be something to be said against welding very old boilers.

With regard to the proposed tests, he did not think they helped one out of practical difficulties. The tests which were made in order to ascertain whether the man who was making the weld was really expert were of little more value than passing him through any other examination. A man might make a good specimen for testing purposes and yet produce a very bad weld in practice. About thirty-five years ago he was sent to Holland to take up the duties of one of Lloyd's Inspectors, who had gone away, and he had there to deal with an iron boiler whose shell plates had been welded. Soon after his arrival it had to be tested, when one of the seams leaked. That was put right by riveting a single strap over the weld. At the next test four other seams leaked, which had also to be covered with straps, until finally all the seams were covered. He was quite sure that boiler ultimately cost much more than if it had been riveted to begin with. Doubtless, in this case the welder was an expert, but a shell plate was clearly too much for him.

A point in the Paper which interested him very much was the fatigue test, but the formula mentioned in the Paper was not to his liking. It gave no fatigue limit; it was a continuous curve. His own formula started with a fatigue limit. He believed that, especially with his formula, the test results would be quite simple; in fact, he had during the last few days come to a very satisfactory conclusion with the help of the fatigue formula about a complicated fracture. He was able to estimate that the fatigue stresses were 2 tons in excess of the fatigue limit, and all that was necessary was either to reduce these stresses by 2 tons or use a stronger material. His formula was: Stress which produces fracture at the Nth repetition = Fatigue limit plus a constant times the fourth root of 1,000,000 divided by N.

$$S = Fl + C\ (10^6/N)^{\frac{1}{4}}.$$

Mention had been made of local heating. It was a common charge against inspectors that they objected to local heating and yet allowed welding, which was certainly local heating. He believed he was the culprit in the matter, for it was due to his Paper on the Injurious Effect of Working Steel at a Blue Heat (Inst. C.E., 1886, vol. lxxxiv, page 114) that the practice of not allowing any local heating in a boiler had since been generally adopted ; but personally, he had never felt quite sure that local heating would invariably produce brittleness. He had certainly seen local heating carried out in boilers which did not result in failure, and now that we were going in for electric welding he did not think that his experiments made thirty-five years ago should hamper a new process. He thought it very desirable that welds should be carefully watched, as they would be watched by the inspectors of his Association, and rules for the future should be based on this new experience. No tests would ever reveal the real nature of every part of an extensive weld. Tests were desirable for research work, but when the research expanded into practical applications, it was as a rule impossible to deal with them on experimental lines.

Mr. E. F. Lang said that one had to consider not only the question of the standardization of the tests, but also the standardization of each kind of weld. In a resistance weld the metal was slowly brought to the welding temperature, then pressure was applied, and when the two bodies intermingled a perfect union was obtained. The process being usually applied to the joining of similar wrought or rolled iron or steel sections, they thus got the nearest approach to hand-welding, in which, when properly done, the mechanical properties of the parts welded were well maintained throughout the weld itself.

In a Paper he had read in March 1918, upon the subject of steel castings, when dealing with the question of the electric welding of steel castings, he introduced a reference to some experiments described in detail in a Paper by Messrs. Stanton and Pannell before the Institution of Civil Engineers in 1912, which showed that the mean tensile strength of hand-welded iron bars was 89·3 per cent of the strength of the original bar, and that the percentage in the case of the hand-welded steel was 81·6 ; with electrically welded

(Mr. E. F. Lang.)

iron 89·2, and with electrically welded steel 93·4. Joints made by the oxy-acetylene process were submitted by two makers, but the results obtained were not comparable with those obtained by hand or electrically.

It would be seen that resistance welding stood in quite another category to fusion welding, in which they had a deposit of molten steel without any work upon it, the weld, therefore, having the structure of a poor quality casting. Personally, he thought the instinct to suspect any kind of electric welding—except, perhaps, resistance welding—was really a very sound one. After all, materials of construction were subject to strict specifications. In the case of plates or forgings the reduction of area from the original ingot represented an enormous amount of work put upon the material. This and the correct working temperatures were essential factors for obtaining the required test results. Therefore, one should not forget that, when repairing such material by arc welding, the new metal thus deposited had undergone neither work nor treatment and was no better than ingot metal, in fact not so good, as the ingot was produced from perfectly de-oxidized and homogeneous molten metal, whilst it was very difficult to maintain good melting conditions with the electric arc.

The human factor entered more into arc electric welding than into any other workshop process. Good welders were born not made, and great experience was necessary before the welder could produce uniform results under varying conditions. He had recently been watching some experiments with covered metal electrodes on work for which it was claimed that such electrodes would give a better result than the Benardos process. Owing, however, to the fact that the operator in the latter case was more experienced than in the former one, the Benardos results were not even equalled by the other. In the case of the flux-covered electrodes, he had noticed the trouble referred to by Mr. Stromeyer, that the operator could not keep the slag, formed by the flux, from solidifying with the metal, although the flux was nominally there to protect the metal from oxidation and give a pure deposit, whereas the Benardos operator, by carefully regulating the arc struck between the carbon electrode and the work, had been able to melt the boiler-plate punchings, which provided the metal for the filling up, in a reducing atmosphere, and got a clean and sound deposit. It had, however, to be remembered that under the most favourable conditions, the metal deposited in arc welding had nothing like the properties of the material it was repairing or replacing ; and in all cases where it was proposed to repair or reconstruct or build up, by means of electric welding, careful consideration should be given as to the part to be played by the welded portion, on the principle that the strength of a chain was its weakest link. Wherever possible, all work for a responsible duty that had been electrically welded should be heat-treated to remove strains. In their own case, all steel castings were carefully re-annealed after electric welding, should this have exceeded the mere removal of surface blemishes.

Mr. H. Carrington said it rather surprised him that the Sankey bending test had not been referred to. This test enabled the tensile strength and the yield-point to be obtained, and the number of bends to fracture, as well as the work done to fracture. The test seemed to combine broadly the three requirements mentioned in the Paper, namely, the tensile test, the bending test, and (to some extent) the fatigue test. He would like to know if it had ever been used for testing welds. Another point with regard to the Sankey test was that it gave consistent results for consistent material, that is to say, if tests were made of unwelded mild steel which had been annealed, the results would be consistent. That was not always the case with other tests, for instance, the Izod impact test for mild steel. The Sankey test was, moreover, a cheap test, the test-piece being only 4 inches long and $\frac{3}{8}$ inch diameter, and information could be got from the inspection of the broken piece afterwards.

There was one other point with regard to the elongation of the tensile test. The elongation consisted of two parts. One part was proportionate to the length of the specimen before the bar began to contract and break, the other part was independent of the length —the local extension due to the contraction. In other words, the relation between the extension and the length was linear. It was,

(Mr. H. Carrington.)

accordingly, possible to separate the two quantities, namely, the constant extension and the extension proportional to the length. Those two, in conjunction with the fact as to whether the test-piece broke at the weld or not, would yield much more information than the simple elongation given upon one length.

Mr. E. M. Ginders said he had heard that the Home Office, in view of their unsatisfactory experience, were considering the advisability of prohibiting the use of welded vessels for pressure purposes. He thought that such a course would be very arbitrary, as those who were now doing excellent work of the character indicated would be penalized on account of others who failed to do so. It was quite easy to prepare nice specimens from the testing machine. It was another matter altogether when they came to operate upon large structures when heat and contraction problems were aggravated. For this reason the testing of the complete structure should receive more attention. One item omitted from the Paper in this connexion was the question of breathing, which should be taken into account. There should be no articulation of the welded joint, to which Mr. Adamson had drawn attention. The welded joint was often deficient in ductility; on this account it should be of greater cross-section than the adjacent material.

Many people attempted the welding of large structures with inadequate plant ; in other cases the structures themselves were of faulty design. These were two prolific sources of failure which would not be reached if we relied exclusively upon the records of test-pieces.

Mr. W. M. Jackson said that for many years, in connexion with his business as a manufacturer of compressed oxygen, he had been very closely associated with oxy-acetylene welding. It was about eighteen years since the first experiments were made at the British Oxygen Company's works in Manchester, and they had found it impossible to hurry on the development of the application of this method of welding owing to the complete absence of any body of trained workmen. They also found it was difficult, not only to train workmen, but even to find suitable men for training, particularly for the welding of iron. He supposed the chief reason for this was the peculiar sensitiveness of iron to heat treatment, and the readiness with which its chemical and physical character was altered by contact with the various gases which played over its molten surface under the flame of the blowpipe or the arc. These difficulties, of course, made a very heavy call upon the operator. They were therefore led to consider very seriously the question of training welders, and some years ago they got into touch with the chief technical schools in England and Scotland and persuaded them to establish classes for the teaching of oxy-acetylene welding. They offered to supply the schools with free outfits and a free supply of oxygen. All the leading colleges established those classes, and during the last seven or eight years very useful work had been done in them for the various districts which they served and for the employers of this class of labour.

The system adopted in the schools was based on one which they had originally worked out to cover a course of theoretical and practical tuition leading up to examinations. On the results of the examinations which were held by the college officials assisted by external examiners, representing employers interested in the subject, certificates were issued, the final one being a certificate of proficiency which was given to advanced students whose welded samples satisfied a series of exacting tests, chiefly tensile and bending. A number of the tests described by the Author were already in use in Manchester, and would only require modification or extension in order to cover the whole field of testing outlined in the Paper.

Seeing that the subject had become of such importance to mechanical engineers, he would suggest that the Institution should associate itself in some way with the Colleges of Technology at Manchester and elsewhere, and be represented on the boards of external examiners. The colleges might then arrange to issue certificates of proficiency endorsed on behalf of the Institution. This would increase their value very considerably. It would also tend further to popularize and standardize the classes.

Another suggestion he would like to make was that the scope

(Mr. W. M. Jackson.)

of the teaching in Manchester and other centres might be extended to electric welding. He thought that engineers who were interested in electric welding might assist the colleges with similar help to that which had been given them in connexion with oxy-acetylene welding. Generally speaking, the only guarantee of good work that one could have was that it had been done by a reliable welder. In the case of repeat work one could, to a certain extent, apply tests, commercial and otherwise, but in the case of repair work it was quite impossible to do that without destroying the work. Even if, as suggested by the Author, a sample were taken from one point in a weld giving satisfactory results, there might yet be in some other part of the weld very serious flaws. Standardization of welding tests was very important and desirable, but standardization of the welder was at present an even more urgent requirement.

Mr. A. H. GOODGER thought it was doubtful if it were necessary as yet to standardize tests. In a welded vessel made to do commercial work, one could hardly apply any satisfactory test without destroying it. There were no means by which knowledge could be obtained of the welds without cutting them out; so it was scarcely necessary as yet to proceed beyond the ordinary tests applied to steel-plates, boiler and riveted joints—which latter were quite as difficult to test as welded joints. Such tests were quite good enough for commercial welded articles at present without going to extremes.

The bending test was one of the most satisfactory tests for oxy-acetylene or electric welds. One could learn more about a weld from a bending test than from any other, and he was very pleased with the appliance which was described for making it in a standard manner. He had been forced to the conclusion that in many cases bend tests adopted were unfair. He had some photographs from makers of welding material, which showed no bending on the weld, but the plates themselves were bent into a circle. That was not a bend test; a bad weld would give a good "bend" if treated that way. It would be a good plan for makers of testing-machines to standardize something like the rig shown in the Paper for fittings to ordinary standard testing-machines.

He did not think there were enough research tests. The tests that were given were very numerous and very expensive, but at the outset it was not desirable to standardize and restrict research tests. He thought one or two tests might be added. First, there was the hot-forge test, which was a very good test because it decided whether there was any red-shortness in the weld. The majority of the electric welds he had come across had been red short, which was due to more or less oxidation of the weld metal, even when flux-covered electrodes were used ; possibly it might be due in some degree to the presence of nitride. But it was a point which was rather vague ; some engineers denied that there was nitride, but he thought it was possible to have it in a weld. A photomicrograph might show there was apparently no oxide present at all, yet the weld or forging might be quite " dry " if bent or forged at red heat. That was due to the fact that, in the passage through the arc, all the impurities of the steel were burned out and the resultant metal was practically a pure iron.

Chemical tests of welds which had been made with Swedish iron, or any soft steel, showed that the weld metal had a percentage composition of about 0·05 carbon, 0·1 manganese, 0·02 phosphorus. Practically everything had disappeared, and it was in perfect condition for taking up oxide. Pure iron which was free from manganese seemed to be capable of dissolving iron oxide and retaining it when it was solid, and this might happen in one of the electric welds made with a very soft steel. To pursue that further, he made various tests of metals of varying carbon content, and varying manganese content, with a view to perfecting some electrodes that he was working on at the time. As he increased the amount of manganese and of carbon in the electrode, so he decreased the " dryness " of the weld until with high manganese and high carbon the weld would bend quite satisfactorily, at a temperature of 800° C. But the higher the manganese or the carbon, the more difficult the electrode was to work with. He came to the conclusion that between those limits there was a point at which an electrode would give the best all-round results. Therefore a hot bend-test should be included in order to determine whether the metal was red short,

(Mr. A. H. Goodger.)

thus indicating a bad and highly oxidized nature of the weld metal.

The Author said (page 234) "In the case of a weld made with metal deposited in a 'V,' the specimen is always tested with the load applied to the side of the specimen which shows the least filled-in metal." He did not think that quite good practice, as it gave the weld the best chance. The weld was most likely to be imperfect on the side indicated, because the welder was working at the bottom of the groove. Generally the bottom of the weld was the least filled, and was the most defective part of the whole weld. The result often showed that there was an incipient fracture. The best thing of all would be to make bend-tests from both sides of the "V." One found very different results with different current strengths; there was no doubt that welds made with a low current did not give as good results as those made with a high current.

The chemical tests should include oxygen and nitrogen. He must admit that the determination of oxygen in steel was difficult, and that opinion differed widely on the matter of nitrogen, yet it probably had considerable effect in arc welds. Did standardization of chemical analyses mean that it had to be up to a certain definite standard every time in regard to carbon, silicon, etc.? His own impression was that the most suitable electrode for electric welding was one which was the least often used. The majority of people liked a very pure material, but his own impression was that it was unsuitable for the reasons he had given.

The Author stated that any excess metal at the weld should be machined off tensile test-pieces. In actual work the weld was seldom machined off. Anyone welding a piece of boiler plate would hardly machine the excess metal off, but would let it remain there for extra strength. Practically all work was subject to use under conditions of no machining, and therefore the tensile test in order to be representative must repeat the conditions and have the excess metal left on it. "Nicking in" was a great defect in electric welding, and often produced localization of stress during tensile test. It would show up badly on an unmachined tensile test-piece if present, but would be removed by machining.

Many engineers seemed doubtful about welds. Recently he had had carried out about forty tensile tests of welds on bars, almost like the standard in the Paper, by a welder without any particular precautions, and in no case did the result come out lower than 25 tons per square inch. The average was 28 tons, the highest 31½ tons. About 25 per cent of the bars broke outside the weld. Some of them broke in the weld, but in very few cases was there anything to distinguish between the result when it broke in the weld or outside the weld, except from the point of view of elongation. He agreed with the Author that the elongation in the weld was of very little use, because one got there a complication of two elongations. An elongation test should be done on a bar made entirely of weld metal. The method of cutting strips out of one plate for testing was undoubtedly good, and was one that he had employed himself.

Before standardization of welds became an accomplished fact, the right thing to do was to help the welder. The lines to go on were to eliminate the difficulties that the welder worked under, give him the best possible apparatus and materials which would make it possible for him to make good welds, even if he were a trifle careless. It was on those lines that development would take place. He himself had a great belief in electric welding, and he thought there was a future for it. He considered that it would not come through testing welds or through the actual electrodes used, but rather through appliances or methods which would eliminate the need for the constant attention on the part of the worker, which he was very often incapable of giving for long periods. Undoubtedly, at the present moment the main thing in electric welding was the skill of the welder. For testing actual work, the only test that he could suggest was a drilling test, so arranged to give an autographic time-penetration curve, thus providing a sort of combined hardness and soundness test. Voids would readily be noted, and a comparison could be made between the metal in the weld, the overheated base metal, and the unheated plate.

Mr. T. A. Rich said the firm, of which he had been the manager for a great number of years, took up acetylene welding in the first instance

(Mr. T. A. Rich.)

for repairs to boilers. As far as the acetylene welding was concerned, the weld itself was quite in order, but the local heating gave them trouble, as when contraction took place a crack developed frequently alongside the weld, and very often in the weld. Therefore they dispensed with the acetylene welding and took up electric arc welding ten years ago. During the first twelve months he had to make tests on his own account, and eventually to the approval of Lloyd's ; in addition he had got ideas from America and Germany regarding welding and flux used, principally from the latter country, the flux being a special mixture which was kept secret. All his firm's welding work on boilers was tested to one and a half times the boiler pressure, when required ; and they obtained 90 per cent tensile stress on test-pieces.

Mr. WILLIAM H. PATCHELL said the remarks of Mr. Rich and Mr. Jackson were very much to the point. Evidently both had done a great deal of testing, and if they would state what their tests had been they would help in settling a proposal for standard tests. In particular, if Mr. Jackson would give them a schedule of his tests and tell them something about the results, so that the value of them could be ascertained, that would be absolutely along the lines that were wanted.

He was afraid the discussion had rather drifted into the question of electric welding against gas welding. They were out to test every weld. He was not a metallurgist, and it was difficult to say where to differentiate between the effect of changes which went on in steel chemically and the changes which were looked upon as mechanical or physical.

Could they get an electric weld without local heating ? He did not think that was possible. They must heat the thing that was going to be welded ; otherwise the weld would not stick ; it would fall out as somebody had said, like a half marble. They had had gas-welding on boilers for years, but the electric weld had not been used in the same way as the gas-weld. He did not know that Fox's flues were electrically welded now ; he thought they were all gas-welded, and nobody was afraid to go to sea, either in the engine-room or in a passenger cabin, behind Fox's flues.

Mr. Carrington had referred to the Sankey bending-test. Of course they could not expect the Author to be as familiar with the President's test as they themselves were. It was one of the simplest and cheapest possible tests, and he had no doubt that when it was better known there would be more confidence in it.

Mr. Ginders said he had learnt that the Home Office had considered the advisability of prohibiting welding for certain vessels. He did not know to what extent it was possible. The Steel Barrel Co. at Uxbridge did an enormous amount of electric welding for pressure vessels, and the manager of those works read a very interesting Paper * before the Institution.

It occurred to him (Mr. Patchell) that they ought to get some of the testing people to deal with the tension, bending, and mechanical testing of the welds. The Chairman (Mr. Adamson) had told him that he could supply some specimens if someone could be got to test them. The Steel Barrel Co., who were working altogether on thin work, would have thin specimens, and if anybody did a little bit in that way—those who were working thick material supplying some and those who worked thin material supplying others—they could get a lot of useful work done at a minimum expense.

A vote of thanks to Mr. **Patchell** was passed unanimously.

Communications.

Mr. F. **Elstob** wrote that the application of mechanical tests must of necessity be severe to be of service, and the danger of permanent and undetected injury to the forging was great. He thought that a careful inspection was preferable, if carried out by an expert welding smith, as was the practice in the North of England thirty years ago. The welding of important engine pieces, such as connecting and eccentric rods, were executed by quite a limited

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* Proceedings, I.Mech.E., 1919, page 49.

(Mr. F. Elstob.)

number of specialized and trustworthy smiths, who were looked upon as welding experts, and failures were very rare. The process of inspection was as follows :—After completing the job, the welded portion was reheated to a good red heat about 800° C., and a small quantity of water was poured on, causing local cooling. The return to full redness was closely watched. Any fault in the weld due to the presence of oxide or cavity interfered with the conductivity of the iron, and caused the return to redness to be retarded over an area immediately over and corresponding with the fault ; faults which did not extend to the surface were detectable by this method. The application of water was repeated at numerous points around the weld ; in some instances the parts would be roughly machined before applying the test.

Sir HENRY FOWLER, K.B.E. (Member of Council), wrote that he quite agreed with the Author when he stated that the field of application of welding had expanded very greatly during recent years, and it was therefore high time that the fullest possible investigation should be made with reference thereto. Further, he was satisfied that engineers in this country were deeply indebted to the Bureau of Welding, established by the American Welding Society, for the steps taken towards the standardization not only of the various phases of welding, but of the details of the inspection and testing thereof.

He would like to support the Author's contention that, in order to arrive at the true quality of a weld, it was necessary to form a comparison with the base or parent metal. The importance of this was surely very obvious, and yet in actual practice the point was very often overlooked. As a matter of fact, several samples of welding had been submitted to the writer quite recently by outside contractors, in connexion with which it was possible to make tests of the welds, but no provision whatever for testing the base or parent metal was allowed. He regretted to say that one such sample came from America, and he appreciated very much that, in addition to suggesting chemical analysis and mechanical tests of such material, the Author had provided for the microstructure of both the weld and parent metal to be ascertained. This was most important, inasmuch as it was surely possible to produce a structure through the process of welding which was quite undesirable. He was also pleased to notice that, in dealing with the standard procedure in the mechanical testing of welds, the Author stated that any excess metal at the weld should be removed " so that the cross-section area throughout the reduced section is constant." He could well believe this was a point which might be opposed by some of the firms who had brought out special welding processes, but in his opinion the Author's contention was perfectly legitimate. He suggested, however, in dealing with the recording of the yield-point in tensile tests of welds, which was certainly most important, that it was now possible to improve on the Author's suggestion that such a value was to be taken by the " drop of the beam " method or with dividers. No feature of a tensile test was more important than this, and probably no other point in the commercial recording of such a test was so unreliable, whereas by using a very simple extensometer like the " Buckton-Kennedy "—with which it was possible to register the elongation of a test-bar to 0·001 of an inch—one had at once a faithful record and an instrument which was most readily attached and detached from the test specimen.

With regard to the inspection of welds in structures, it was common knowledge that in many instances the operation of welding was carried out upon material in the way of repairing the same, such articles as the following coming within that category from a locomotive engineer's standpoint :—Engine and tender-frame plates, buffer beams, steel gussets, and splasher plates and angles, and in these cases it was of course quite impossible to carry out the tests previously suggested. The human element thus became the predominating factor, and anything that could be done in the suggested direction as to a standardized test for the proficiency of men engaged on such work would surely be to the good of all concerned.

Mr. THOMAS T. HEATON wrote he had noted in the discussion that Brig.-General Bagnall-Wild stated that the testing of welds had never been thoroughly discussed in England. He presumed that

(Mr. Thomas T. Heaton.)

General Bagnall-Wild was occupied in connexion with the concluding arrangements connected with the War, or he would have had an opportunity of reading the writer's own Paper on Electric Welding * read before the Institution. In that Paper, under the head "Testing," this question was fairly fully discussed and a number of suggestions made for carrying out tests, both for the purpose of discovering the amount of skill used by the welder and for the purpose of discovering the strengths and soundness of welds themselves; and illustrations of apparatus were exhibited for specially testing the skill of the welders, some of which were very similar to those described by Mr. Farmer. He thought it was a very serious omission from Mr. Farmer's Paper that there was no suggestion as to what, in the writer's opinion, was the real necessity of the matter, namely, the testing of welds in order to prove their value in work of a constructional nature, and to ensure that they were adequate for the purpose.

He (Mr. Heaton) had had experience of cases in which a skilled welder had been employed to do certain work, and had proved that he was capable of doing it effectually, but, when called upon to repeat it on a large scale, had failed to produce good welds. It was all very well to employ a skilled welder who might be proved to be so, but, unless his work was properly tested after completion, there was no guarantee against carelessness or loss of attention, and this was where electric welding might show weakness. It would be of great value if standard tests could be devised for all kinds of welded joints. The number and variety of joints, however, was so great that it would be far from easy to specify standard tests. There was no doubt that tests were required for all welds, and he thought they should be standardized as far as possible. Probably a committee of engineers, consisting to a considerable extent of those practising electric welding, might produce something effective in this direction.

Mr. F. C. Hibberd wrote that, as the Author rightly pointed out,

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* Proceedings, I.Mech.E., 1919, page 49.

the present basis comparison of strength was between that of a welded joint and the parent metal. The writer recently had an opportunity of carrying out certain tests on welded plates from $\frac{1}{4}$ inch to 1 inch thick inclusive, and the average tensile efficiency of the welded joints was about 97 per cent, showing that the welding art had already arrived at a stage at which a welded joint could be made practically as strong as that of the unjointed metal. In a Paper read before this Institution by Dr. W. H. Hatfield,* the question was raised as to the value of various tests now more or less recognized as standards for obtaining knowledge of the physical characteristics of steel. Dr. Hatfield's conclusions were :—

(1) That all different forms of tests which have been devised for the mechanical testing of steel bring out some information of interest. The information, however, derived from any particular test needs carefully considering by the engineer in relation to the kind of work which he is calling upon his part to do.

(4) The tensile test is fundamental, the other forms of mechanical testing being auxiliary and useful in their way for supplementing our knowledge of steels when required for specific purposes.

Seeing that in the present stage of the welding art our object was to achieve physical characteristics exactly similar to those of the unwelded metal, surely the above remarks applied equally to welded metals. In the latter case, however, the human element was ever present in a marked degree, and there was but little doubt that in addition to any standardized system of testing, such preliminary precautions as the training and examination of welders, and a regular examination of their work whilst in progress was of paramount importance.

The importance of metallographic records could not be exaggerated, and whilst the Author was quite correct in specifying that such shall find a regular place in his proposed "Research Standard," it would appear that if only as a check upon the work of the operator, they should also find a place in his proposed "Commercial Standard," and even in his "Shop Standard" also. The writer would suggest that such records should be made at

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* Proceedings, I.Mech.E., 1919, page 347.

(Mr. F. C. Hibberd.)

450 diameters, as it was doubtful whether the proposed photographs at 100 diameters only would reveal all defects. Figs. 13–16, Plate 15, illustrating welds taken at 450 diameters, would show the advantages of the greater magnification, and they also served to show the degree of skill of the operator and the correct analysis of the electrode material.

The question of the analysis of the electrode had already become a matter of metallurgical study. Briefly, assuming that the object of welding was to produce a joint showing the same characteristics as the parent metal, it was obvious that a suitable electrode was composed of the same elements as that of the metal to be welded, with an excess of those elements which were partly burnt out during the welding process. From this it followed that the Author's suggestion that, in the future, welds might be produced having inherent characteristics such that welds might be introduced into a structure for the sake of acquiring these characteristics, was quite within the region of practical possibility; in fact such results could already be produced without difficulty if required.

In cases where parts were subjected to alternating expansion and contraction, for example, boilers, the fatigue test referred to by the Author was of the utmost value; welded specimens had been known to stand ten million revolutions in a machine similar to that illustrated and described by the Author.

Mr. E. H. JONES wrote that the standardization of tests in connexion with welds was desirable, but such tests should include some form of shock test. In the early days, welders found difficulty in avoiding brittle welds, and although these welds might give very good results when subjected to a tensile test, yet they failed very readily under a shock or bending test. The Author's suggestion that the workshop test should be a bending one was very good, for if a weld would stand a good bending test, it was certain to give good results with all other tests. As a good rough and ready test, nothing could excel the breaking of a specimen along the line of the weld by holding it in a vice and hammering the free end. The resulting fracture would give the expert welder practically all the information be required, and such a test would also give the inexpert welder information which would generally cure his self-esteem. For the testing of welds *in situ*, the use of a fine drill would assist in demonstrating whether a sufficient body of satisfactory metal existed in the weld. The fine holes drilled could very easily be opened out with the arc and welded up afterwards.

Lloyd's Register were to be heartily commended for the steps they had taken to ensure that the materials used either for the construction or repair of vessels built or repaired under their regulations were of a satisfactory quality. Their approval virtually placed a hall-mark upon material approved by them, and such approved material could be used with every confidence ; and if the welder possessed the necessary degree of skill, there was very little risk of the welded work being unsatisfactory. Every new industry had difficulty due to inexperienced workmen, and there were unfortunately many men claiming to be welders who were unfit to carry out such work, and it seemed very important that the workmen should be tested as well as the work.

Mr. H. OGDEN wrote that the standard tests suggested by the Author were not, in his opinion, the most serviceable. In ordinary shop practice the simple bending test, occasionally varied with a tensile test or some novel test, served to make welders of the right stamp keen on their work, and the shop standard should not be limited to any one test. A novel shop test recently carried out by the British Arc Welding Co. took the form of making a 14-inch welded cylinder of ⅜-inch boiler-plate, also welding on dished ends. The cylinder had withstood a hydraulic pressure of 4,500 lb. per square inch without fracture, showing that the welder put in good work. This pressure represented a stress of 22 tons to the square inch, or thereabouts, across the longitudinal seam.

With regard to the Standard commercial tests, Lloyd's Register had instituted the first Standard commercial tests for firms intending to apply arc welding to shipbuilding. He was of opinion that Lloyd's set of tests was more useful than the set proposed by the Author. The chief points of divergence were that Lloyd's omitted

(Mr. H. Ogden.)

the bending test and included an impact test, a test of built-up material, and tensile tests of 300 tons specimen welds, besides other non-mechanical tests.

With regard to the bending test applied to welds, the information given was of doubtful value, just in the same way as the percentage of elongation in a tensile test. The whole of the bending was often taken by the plate adjacent to the weld. If, however, special notes were made of the amount of bend actually taken by the weld, this test would be of more value. He was distinctly in favour of testing the weld with the bottom of the V towards the actuating block. This gave the more rigorous test of the two alternatives. One of the speakers at the Meeting disagreed with this point on the grounds that welders were in the habit of leaving voids at the apex of the V. Such a thing was unpardonable. He thought that an impact test gave more useful information than a static bending test. A large 300-ton tensile test-piece should give the same relative result as the smaller one described by the Author.

With regard to the research standard, he felt inclined to let research look after itself. Research could not be standardized, and it should not be shackled with even a limited degree of standardization. He noted, however, that the Author did not include X-ray photos of welds in his scheme. These would yield very valuable information relative to the soundness of the weld, which could only be obtained in other ways by the most laborious process of slowly destroying the weld. Further, the weld after being X-rayed could be tested in any selected test.

With regard to the standardization of welders, in this country individual lines were generally preferred, with the result that each works developed its own system of securing good welders and good work. Within such works, some standardized system of inspection might prove effective, whereas in other works with a different personnel the same system might break down.

Mr. R. J. A. PEARSON wrote that, in any system of testing, it would be necessary to regard the welding operations under one or other of six headings: (1) Gas welding (oxy-acetylene); (2)

Welding by carbon arc; (3) Welding by quasi arc; (4) Butt welding; (5) Spot welding; and (6) Continuous strip welding. Of the above, in the first three the heat was produced either by a gas-flame or an arc-flame. In the last three the heat was produced by resistance to a heavy electric current at low voltage. The temperature to which the material was raised, and the extent of the area affected, would vary in accordance with which of the above systems had been employed for effecting the weld. A definition of the process was therefore essential.

The Author had not enlarged on the use of welding for effecting repairs; in practice this was carried out on a large scale, especially on steel castings. The welding of steel castings, which were subject to official inspection, had always given rise to controversy and differences of opinion, but in many instances was the only course possible for saving an expensive steel casting. Welding was now used for effecting joints which had to withstand high steam-pressures, and the experience of some large boilermakers was available in support of the safety of this procedure.

With regard to the standardization of welders, any such grading would have to be based on the nature of the work they were capable of and required to do. Of the welding carried out to-day, 90 per cent could be quite easily learned by a handy labourer in a few weeks' time, but natural aptitude and months of training were required for carrying out welds on boiler joints to withstand high pressure successfully, though here again experience seemed to show that the handy labourer was the best raw material for training up to these duties.

Mr. G. H. ROBERTS, C.B.E., wrote that he realized the difficulties in the way of standardization, largely due in his opinion to the fact that a weld, truly considered was not exactly an entity in the sense that any one of a batch was necessarily identical with any other as regards its principal characteristics and properties. In speaking of the standardization of certain classes of steel, for example, one might be fairly sure that with reasonable care any one of, say, a dozen test-bars cut from the samples produced under like conditions would be

(Mr. G. H. Roberts.)

fairly certain to have similar properties, but any one weld out of a dozen might reveal properties vastly different from the remainder, owing to slight and usually accidental differences in the method of production.

The Author (page 226) referred to the differences in details of procedure in the making of tests as having caused such widely divergent results that comparisons were frequently impossible. The writer considered that this was an extremely important point and one that many others encountered frequently when attempting to compare work done by researchers and experimenters in different parts of the world. The Author said (page 227) that "sometime in the future, processes may be developed which will produce welds having inherent characteristics, such that welds may be introduced into a structure for the sake of acquiring these characteristics." The writer found some difficulty in apprehending exactly the Author's meaning in this case, and he could not imagine any circumstances in which a weld would be so introduced.

The Author proposed (page 229) under Section C (2) to deposit ingots of filled-in metal in a base metal mould, etc. ; the writer again felt some difficulty in apprehending the exact meaning or intention in this case.

The Author proposed (page 231) a standardized form of test-piece, but the writer regretted to see that this did not comply with the standards laid down by the British Engineering Standards Association, standards which, as was well known, had already been widely adopted in this country and elsewhere. Adoption of the American standard would tend to bring about the difficulty to which the Author himself had previously referred on page 226.

On page 232, the Author suggested "the rate of movement of the cross-head of the testing machine should not exceed that at which the beam can be kept accurately balanced at all times." It was well known that considerable differences, particularly of elongation, might result from different speeds of straining, and as this was again largely dependent upon the particular type of testing machine in use, constriction in the supply pipes, etc., he would like to suggest a limiting speed of so many inches per minute, the actual figure to be a matter for discussion.

The Author (page 234) spoke of noting the instant the first crack appeared in the specimen whilst being bent. No doubt he was speaking from actual experience, but the writer, from his own experience and examination of considerable numbers of welded specimens under bend test, was of the opinion that this exact instant was not always easy of determination, as the first " crack " was not infrequently merely a slight uplifting of the edge of the scarf or weld.

The method of obtaining samples for the special testing machine was described (page 239), but the writer imagined that there would be a considerable variation in the results obtained, having regard to the fact that no definite proportion of " weld metal " to " base metal " was laid down. In connexion with the use of this particular form of testing machine, it would be of interest to know whether the Author, or Professor Moore, or anyone else, had taken observations of the local heating, or the variation of electrical resistance during the course of a test, as it would appear not improbable that there might be some connexion between the condition of the weld and these two quantities.

Barba's Law was quoted (page 242) as " the ratio of the gauge length to the square root of the area should be a constant." The writer thought that this was hardly the form in which M. Barba had propounded his law, which was rather a statement that " the deformations of homologous—that is, similar—test-bars, are similar," but the form now stated by the Author was merely a derivative of this, and for many purposes a more convenient one. The writer regretted to see lower down on page 242 that the Author suggested yet another value of the constant $\frac{L}{\sqrt{a}}$ and failed to see why the constant hitherto adopted of either 4 or 8 or 11·3 in the metric system could not have been adopted and so rendered the results and investigations more easily comparable.

The writer considered that the " inspection and tests of welds in structures " (page 244) was perhaps the most important point in

(Mr. G. H. Roberts.)

the Paper. He was himself interested in the welding of such structures as steam-boilers, where no amount of testing of samples could guarantee that a good job had been made of the welding of the actual boiler itself. The ordinary methods of examination were not of much use, nor was hydraulic testing.

Mr. C. HUMPHREY WINGFIELD was heartily in agreement with the Author as to the desirability of standardizing reliable methods of testing welded joints ; more especially those in actual structures, as, owing to their great liability to extreme want of homogeneity, there was no guarantee, and indeed little likelihood, of "test-welds" made separately being at all representative of the quality of a particular welded joint. He doubted whether a responsible engineer would generally be willing to allow a piece of a welded joint to be scooped out—cheese-taster fashion—as was suggested (page 244), apparently in all seriousness. Even if the result of such a test were excellent, it might in no way represent the general condition of the joint. Notwithstanding the conclusion of the Committee described on page 244, he felt that the only practical test in actual structures would be some development of the induction, electrical resistance or magnetic methods. (Since he described two of these,* a British patent had been granted to a German inventor for a modification of the "Hughes" balance, in which a specially constructed horse-shoe magnet was passed along a bar containing a weld or fault : this combined the Hughes and Saxby methods.)

With reference to "test welds," which were no doubt of use in the laboratory for ascertaining the welding qualities of different kinds of steel and the best conditions for welding them, he felt that, until Professor H. F. Moore's opinion (page 242) received independent confirmation, it was preferable to conform as far as possible with Barba's law of similarity : and, with this in view, he asked whether there was any objection to making "R" (in Fig. 2) $= 2t$ and "W" $= 3\frac{1}{4}t$? For the $\frac{1}{2}$-inch plates, which he understood were the only ones yet tried, this would involve no alteration, while the proportions would remain constant for other sizes. He did not know whether the "standard flexure formula" referred to near the bottom of page 234 was

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* Proc. Inst.C.E., vol. lxxxviii, pages 54, 55.

$$\text{Stress} = 1 \cdot 5 \times \text{Load} \times \frac{\text{distance between supported points,}}{b\,t^2}$$

but this was inapplicable where the stress, as in this case, exceeded the elastic limit. ("W," of course, was not the distance between supported points, which would have to be measured for each test.) The fact that the fracture always occurred at the load-bearings showed that it depended on the machine rather than on the specimen, and the diameter should invariably be reduced as described on page 240. While agreeing that a number of small specimens had the advantage (claimed on the same page) of determining the degree of uniformity of a long weld, he wished to emphasize the point that this degree might be entirely different on another joint made under similar conditions, and was therefore no indication of its value. He would like to point out the advantage of averaging such a series of tests by some such method as the one which he had devised and published in *Engineering*,* as this eliminated abnormal results, which would otherwise influence the conclusion arrived at.

Mr. F. M. FARMER wrote that he was very appreciative of the reception extended to his Paper. Its primary purpose was to elicit opinions on the general proposition of standardization and particularly on some of the suggestions put forward. Apparently this purpose had been accomplished, because much of the discussion was of a constructive character and would contribute very definitely toward the ultimate accomplishment of standardization in this direction.

The remarks of most of the speakers did not appear to call for a direct response. However, two points were raised to which reference should be made. One was the suggestion made by a number of speakers that some form of impact test should be included in the proposed schedules. The Author was inclined to agree with

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* *Engineering*, vol. civ, page 226.

(Mr. F. M. Farmer.)

this view, and since the Paper was prepared there had been some discussion in the United States of a form of impact test which would be applicable as a commercial standard and possibly also as a shop standard; it seemed highly probable that ultimately such a test would be devised.

The other matter was the apparent failure to recognize the work of Messrs. Abell and Heaton. The Author was quite well aware that these gentlemen, as well as many other distinguished English engineers, had done a great deal of work in this particular field, work which was recognized as having contributed very greatly to the advance of the welding art. As the Paper was primarily of a general character and did not purport to propose anything that was specially new or novel, it did not seem necessary to refer individually to the many developments in the testing of welds which formed the basis of many of the standard tests recommended by the Author in his various proposed schedules.

JOINT MEETING OF

The Institution of Mechanical Engineers

WITH THE

Society of Chemical Industry.

PROCEEDINGS.

4TH MARCH 1921.

A JOINT MEETING of The Institution of Mechanical Engineers with The Society of Chemical Industry was held at The Institution, London, on Friday, 4th March 1921, at Six o'clock p.m.; Captain H. RIALL SANKEY, C.B., C.B.E., R.E. (ret.) *President*, was in the Chair, supported by Sir WILLIAM POPE, K.B.E., F.R.S., President of The Society of Chemical Industry.

The PRESIDENT remarked on the nature of the Meeting, because it was a Joint Meeting between this Institution and the Society of Chemical Industry. He was glad to announce that Sir William Pope, the President of that Society, and several important members of the Society were present. M. Paul Kestner, the Author of the Paper, was the President and Founder of the Society of Chemical Industry in France. He was a very well-known French Chemist and an Engineer, who had done much work in connexion with sugar refining, multiple evaporators, and other matters of a similar nature.

The following Paper was read :—

"Degassing and Purification of Boiler Feed-Water"; by PAUL KESTNER, of Paris.

The Meeting terminated at Eight o'clock. The attendance was 168, including 50 Members of the Society of Chemical Industry.

DEGASSING AND PURIFICATION OF BOILER FEED-WATER.

By Paul KESTNER, of Paris.

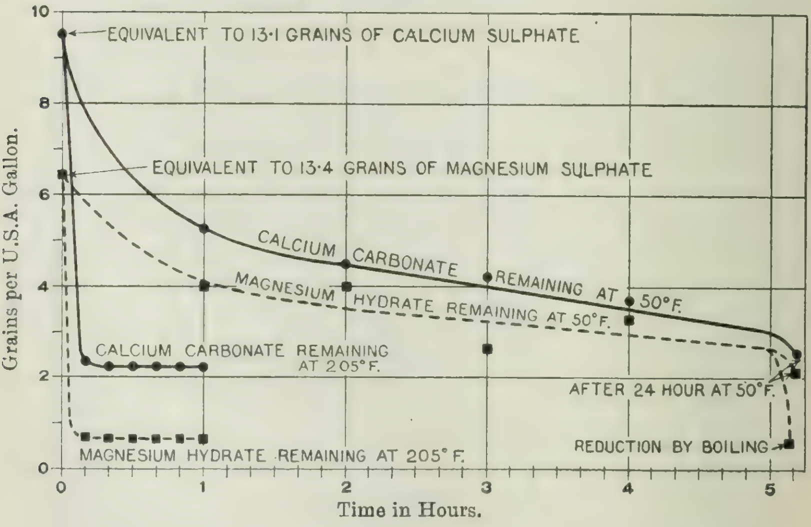
How to feed boilers with water and to enable them to run for long periods under steam without scale or corrosion is the problem which becomes more urgent every day, and further, it is a problem on which a great economy of fuel and material depends. It is certain that a large number of technical men have already attacked the problem—frequently with considerable success, but never with complete success. The old lime and soda purifying apparatus, of very large dimensions, has been gradually replaced by apparatus of a much smaller size in which, thanks to the arrangements which will be discussed, the rate at which purification is effected has been increased. Lately, purification has been done by heating, which has accelerated the process. In spite of these efforts, some kinds of water have proved refractory to treatment; after addition of lime and soda, when raised to high temperatures, they have still given rise to scale in the boilers. A process which has been effective with one kind of water has given only indifferent results when used with another water. Another process which has eliminated all calcareous salts from the water has, in some boilers produced a concentrated solution of soda. Perfect purification is rarely obtained.

There is, however, a process which ensures the prevention of the formation of mud and incrustation in boilers. This process, which is that of continuous blowing-down, will be considered in this Paper. It is necessarily used in conjunction with the hot purification process, and the combination constitutes a complete method of treating the boiler feed-water.

Purification at High Temperature.—It is unnecessary to recall the advantages of feeding boilers with hot water. In addition to those advantages due to the thermal side of the question, there are those produced by the reduced solubility of gases in water at high temperatures, as will be shown. Purification at ordinary temperatures, whether by the use of soda alone or lime and soda, requires considerable time, owing to the slowness of the reaction and the fineness of the precipitate formed, which settles very slowly. The reduction in the time required for the same reactions in hot and cold liquid is shown in the curves, Fig. 1, which has been taken from a catalogue published by Messrs. Cochran and Co.

FIG. 1.

Curves showing Reduction in Time required for the same Reactions in Hot and Cold Liquids.



Ingenious processes have been invented for enabling the speed of these reactions to be increased and to hasten precipitation in cold water. This consists in bubbling through the sediment in the water to be purified after the addition of the reagents. Under the influence of the large quantity of old residues, the size of the particles that are formed increases; the small particles that come into existence are attracted by the larger ones that have already formed which absorb them, and this precipitate, which consists of much coarser material, settles very much more rapidly. Owing to the increased speed of settling, the reagent quickly becomes poor in one of its constituents, and the equilibrium of the reaction is favourably disturbed. This process allows the rate of purification to be increased, and hence the dimensions of the apparatus can be reduced; but, on the other hand, a difficulty is generally introduced where agitation of the sediment is obtained by a stream of water which carries air with it. This causes a considerable increase in the amount of oxygen contained in the water that is to be purified; under the conditions met with in practice saturation occurs almost instantaneously and gives rise to corrosion in boilers.

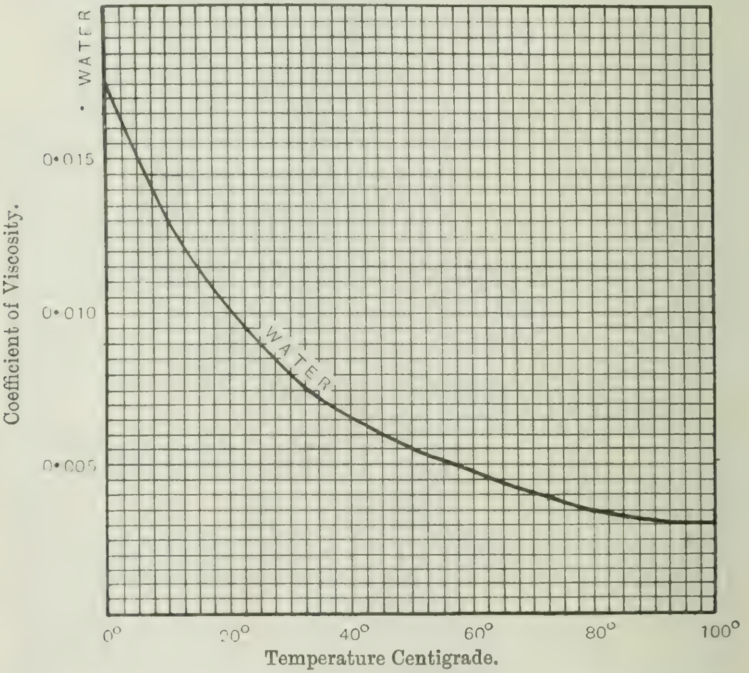
In any process for softening water, a rise of temperature gives the following advantages:—

(1) *Increase of the Speed of Reaction.*—For the same initial concentration, equilibrium is obtained, as is well known, more rapidly at higher temperatures than at the temperature of the air. This follows from the laws of Guldberg and Wage, Gibbs and Le Chatelier, to which there is no reason to refer further. We need only mention that at the temperature of absolute zero, i.e.,—273° C. reactions have no speed at all, and that any rise of temperature increases the speed of obtaining equilibrium in any reaction. In the case of the reactions with which we are concerned, and which are of the character of double decomposition, equilibrium is only slightly affected by rise of temperature, but the speed at which it is obtained is enormously increased.

(2) *Diminution of the Viscosity of the Water.*—The coefficients of viscosity decrease very rapidly as is shown by the following curve, Fig. 2 (page 294).

Viscosity is the chief resistance which is opposed on the one hand to molecular attraction of the particles of the precipitate towards each other in the formation of larger aggregations, and on the other hand to the settlement of the particles formed from suspension in the solution in which the precipitate has been produced till they reach the bottom of the containing vessel. The coefficient of viscosity is the tangential force required to displace an unit area at unit velocity in the medium under consideration. It will be seen, therefore, that the rate of forming a granular precipitate depending on molecular attraction will, other things being equal, be directly proportional to the coefficient of viscosity. The velocity of falling of a spherical particle having a density greater than water will be given by Stokes's formula.

FIG. 2.—*Curves showing Rapid Decrease of the Coefficients of Viscosity.*



$$V = \frac{2}{9} \cdot \frac{D-d}{N} \cdot g \cdot r^2,$$

in which V is the velocity, D the density of the particle, d the density of the water, g the acceleration due to gravity, r the radius of the particle, and N the coefficient of absolute viscosity.

If we examine the curve of coefficients of viscosity, we shall find that this maximum velocity of falling will, under some conditions, be four times as great at 100° C. as it is at 12·5° C. We may therefore deduce that the deposition of a sediment will be four times more rapid with water at boiling point, and that the volume of the purifier may be reduced in the same proportion.

(3) *Decomposition of the Bicarbonates of the Alkaline Earths.*—The direct effect of temperature on bicarbonates of the alkaline earths is to decompose them at 70° C. into carbonic acid gas and the carbonates of the alkaline earths, without the addition of any reagent.

(4) *The Diminution in the Solubility of Sulphate of Calcium.*—Sulphate of calcium becomes reduced at higher temperatures and the precipitation of part of this salt is effected without the intervention of chemical reagents. This reduction is of very slight importance in the process using continuous blow-down, just as the increase of solubility of calcium carbonate is a negligible factor. We shall see later why these facts have so small an influence in the particular case under consideration.

Continuous Blow-down.—When a boiler, the feed-water for which is purified by any method, has been running for some time, all the salts carried in with the feed-water are concentrated in it. These salts are only alkaline salts when the water has been thoroughly purified, and the calcareous sediment of the water has been incompletely purified. In general, a definite amount of calcium carbonate always remains in solution in the water. When the concentration produced by evaporation becomes so high that, notwithstanding the rise of temperature, this carbonate remains insoluble, it is then deposited on the walls of the boiler and in the tubes forming incrustation, which is the harder the more slowly the deposit is made. In boilers generating steam very rapidly, these deposits are formed more rapidly than in slow evaporation boilers, and notwithstanding the violent circulation of the water, sediment may accumulate in the tubes. These sediments give rise to overheating and to very hard incrustation.

To avoid these difficulties, in actual practice, the boiler is blown off, that is, at the lowest point on the boiler shell, the water containing the collected mud is drawn off and turned into the drain. This water is at the pressure and temperature of the boiler, and, in blowing off, a large quantity of heat is lost. To be effective, blowing off must take place to the extent of a large actual quantity of water, though the amount is small in proportion to the total contents of the boiler. Continuous blow-down allows these calories to be saved. Instead of sending the blow-off direct into the drain a relatively small quantity is caused to leave the boiler continuously from its lowest point. This water cools in giving up its calories to the feed-water in a feed-water heater of ordinary pattern; the mud is deposited in a trap; it loses in cooling a certain proportion of the salts which had been retained in solution owing to the high temperature of the liquid. Then, the salts which would cause incrustation, mud and deposit having been collected and removed, the liquid is mixed with the feed-water and returns into the boiler. It will thus be seen that there is no loss of calories due to the blow-off, and that neither deposition nor scale can be caused in the boiler. There is, however, another cleansing operation to perform. It is the removal of the mud deposit at the blow-off outside the boiler. This removal is only of small magnitude, because the apparatus in which precipitation takes place has a conical bottom suited to this purpose; and, further, the water in it is not under pressure; it removes only a few calories because the blow-off water is at this moment already considerably cooled. This small amount of extraction at low temperature completely suffices to limit the concentration of the soluble salts before danger from the raising of the boiling point of the water commences.

If the boiler has been blown down to the extent of 20 per cent of its contents in an hour, this means that its contents are renewed every five hours. This is impossible to effect by any other process, and it ensures the elimination of all mud that has been produced before it has had time to accumulate. This shows the great advantage presented by the process of continuous blowing-down in itself, this advantage being twofold when the feed-water is purified by means of soda; in fact, in this case, the calcareous and magnesium bicarbonates contained in the water give, by double decomposition with sodium carbonate, sodium bicarbonate and calcareous carbonates according to the reaction :—

$$(CO_3)_2\,Ca\,H_2 + CO_3\,Na_2 = 2\,CO_3\,Na\,H + CO_3\,Ca.$$

The bicarbonate, which is unstable at the temperature at which the purification in hot water takes place, decomposes, at any rate partially, giving a neutral carbonate and carbonic acid gas, according to the equation

$$2\,CO_3\,NaH = CO_2 + H_2O + CO_3\,Na_2.$$

The water which enters the boiler contains, therefore, carbonate and bicarbonate of soda. These salts are in quantities equivalent to the calcareous salts that have been eliminated. In the boiler the bicarbonate is decomposed, giving a carbonate, as has been seen above, and then the carbonate in its turn is dissociated in the presence of water, giving caustic soda. There is thus another reversible condition of equilibrium in functions of the initial concentration on the one hand and of the temperature on the other. This may be represented in the following form :—

$$CO_3\,Na_2 + H_2O = 2\,Na\,OH + CO_2.$$

Thus hydrolysis gives more caustic soda, the higher the temperature.

With continuous blowing-down, water containing caustic soda and carbonate of soda is therefore drawn from the boiler. If this solution be mixed with untreated water, the caustic soda and the carbonate they contain will purify the water; the carbonate in the same manner as previously mentioned, and the caustic soda in the following manner :—

$$(CO_3)_2\,Ca\,H_2 + 2\,Na\,OH = CO_3\,Na_2 + 2\,H_2O + CO_3\,Ca.$$

The caustic soda reacts on the calcium bicarbonate as would calcium oxide, but much more rapidly. New products will then be formed, namely, sodium carbonate and bicarbonate, which will be returned to the boiler.

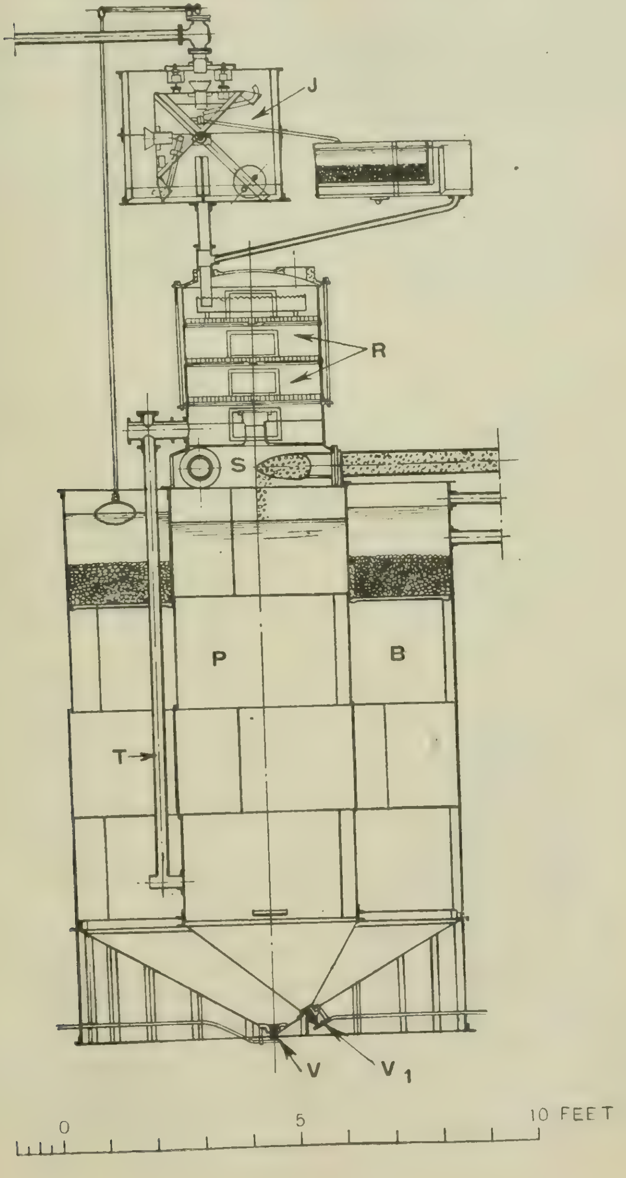
If the quantity of blowing-down is calculated in such a manner that it brings down the quantity of soda necessary in a given time for the purification of the water entering the boiler in the same time, it will be seen that it will not be necessary to add any carbonate of soda for purification of the temporary hardness of the water. A closed circuit will be formed containing a certain quantity of soda, which will never be exceeded. The soda is never concentrated in the boiler, because no fresh soda is introduced. The concentration in the boiler depends on the proportion of blow-down in relation to the feed-water. The less the quantity of blow-down, the greater will the concentration become, so that the same quantity of salt will be contained in a smaller volume.

It is therefore of the greatest importance to combine purification by soda with the continuous blow-down. This allows of more economical use of the chemical reagents necessary for freeing the water from the bicarbonates of the alkaline earths. Consequently, owing to the circulation of the blow-down through the purifier, there is a blowing through the deposit favourable to drawing-off and purification at high temperature by using the calories that would be thrown away in the drain under ordinary methods of blowing-off. The concentration of the soda in the boiler is limited, and neither deposit nor incrustation can be produced. The consumption of soda is reduced to that necessary for the decomposition of non-carbonates. The Author has devised the following apparatus using a blow-down on the preceding principle, Fig. 3.

This apparatus consists of a steam separator S into which the blow-down enters in the form of a mixture of steam and water. The liquid from the blow-down falls into a central reservoir P, in which it gives up its heat to the water surrounding it in the annular chamber B, into which it is decanted.

The steam from the blow-down rises in the reheater R, in which it reheats the feed-water, which loses a part of its bicarbonate

FIG. 3.—*Blow-down Apparatus enabling the Thermal and Chemical Properties to be saved.* (Kestner.)



owing to the rise of temperature. The water thus heated falls through the tube T and mixes with the blow-down as it leaves the central chamber, and then rises in the annular chamber B, in which precipitation and settlement take place. Reheated by admixture with the blow-down, as well as by exchange of heat with the central vessel, the purified water passes through the filter and enters the boiler. The soda is distributed in the apparatus by means of a water-meter J, which admits it in proportion to the new water (make-up feed). The valves V and V_r allow the mud to be separated. This apparatus enables the thermal and chemical properties of the blow-down to be utilized, or, in other words, heat and chemicals are saved.

Position of the Blow-down.—It is necessary to arrange the blow-down at the lowest possible level on the boiler without risk of emptying it. A simple arrangement is recommended by which, when the water of the boiler falls below a certain level, the siphon action of the blow-off is destroyed. At this moment steam leaves by the inlet and calls attention by sounding a whistle. In any case it is impossible to empty the boiler by the continuous blow-down, Fig. 4.

On the pipe of the continuous blow-down and the outlet from the boiler, a reducing valve is placed, which reduces the pressure of the blow-down from that of the boiler to a pressure of between one and two kilogrammes per square centimetre (15 to 30 lb. per sq. in.) before it enters the purifier. In order to allow of the amount of the blow-down being regular, a meter is placed at the outlet of the boiler and is fitted with a regulating valve, Figs. 5 and 6.

Proportions of the Blow-down.—The proportions of the blow-down are calculated according to the temperature to be maintained in the purifier. It is always desirable that the temperature at which purification is effected should not be less than 70° C. According to the working pressure of the boiler, various rates of blow-down may be used, and these can be obtained by the curves, Fig. 7 (page 302).

FIG. 4.—*Continuous Blow-down.*

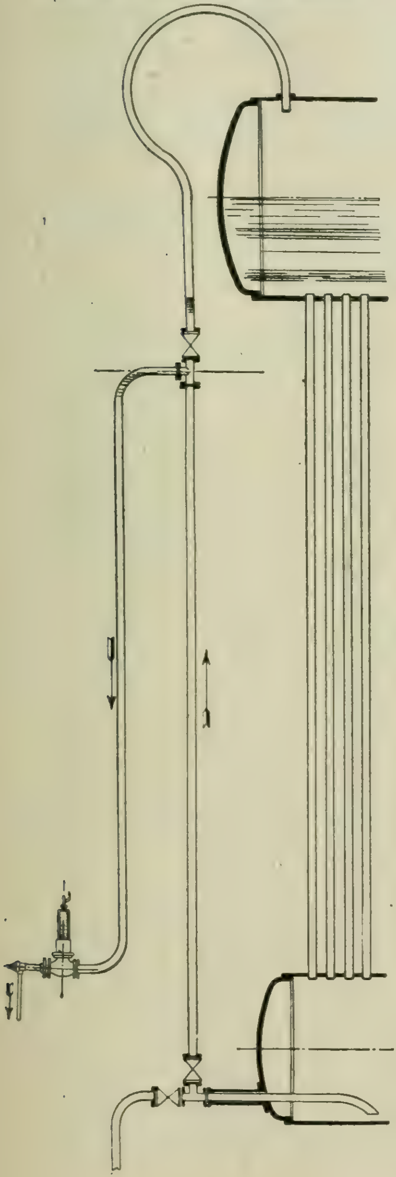


FIG. 5.—*Regulating Valve.*

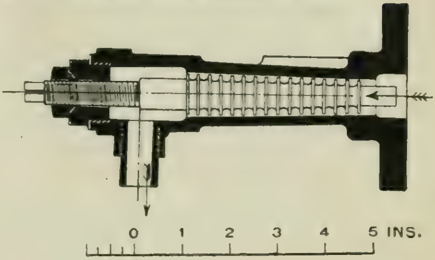
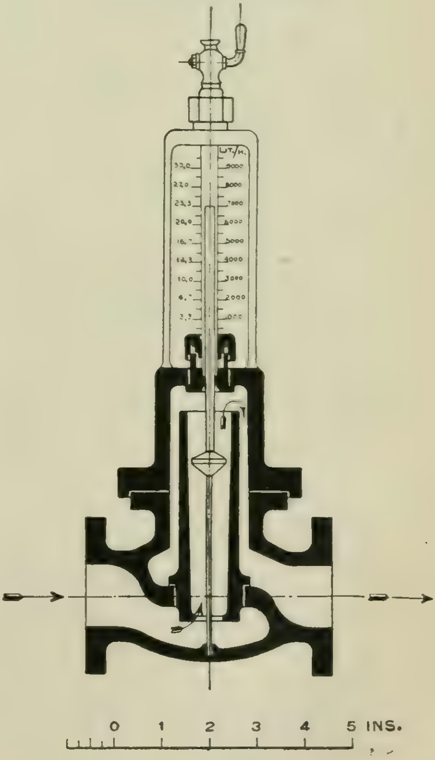


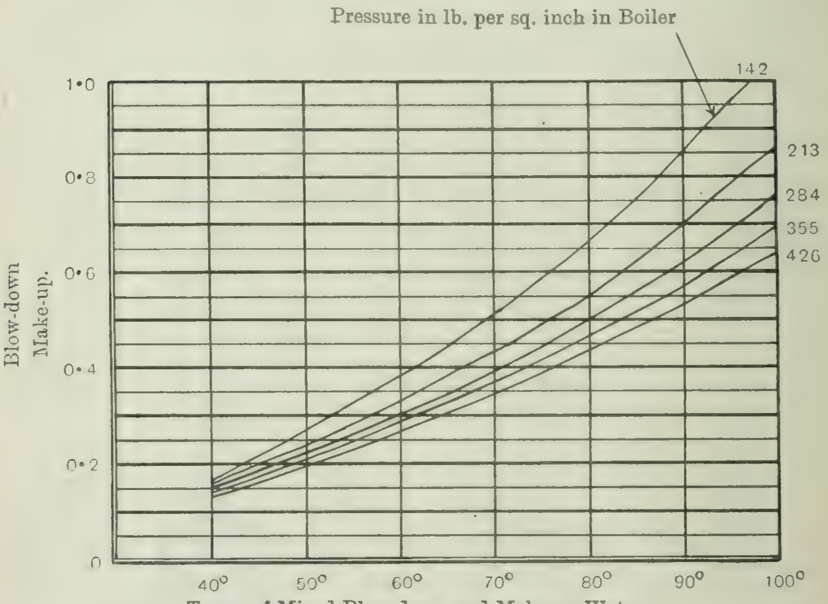
FIG. 6.—*Flow Indicator.*



The temperature at which the water leaves the purifier, although very nearly 100° C., allows of the use of an economiser, as has been shown by recent researches in France.

Central Stations using Distilled Water.—It has just been shown how the system of continuous blow-down can be applied to a boiler using purified water. A case offering still greater interest is that of central stations using distilled water.

Fig. 7.—*Curve showing Temperature of Water leaving Heater Settler.* (*Water Purification.*)



The distilled water of industrial appliances differs greatly from the distilled water of the laboratory. In these appliances, it is necessary to blow down the boilers as a concentration of the boiler contents arises, due to the entry of salts through accidental leakages of impure water in the condensating plant; thus the water that has been distilled contains numerous soluble salts, present in smaller proportions than in purified water, but by no means negligible. The following relationship is found to exist between the water in the boiler and the water of distillation:—

——	Untreated Water.	Distilled Water.	Proportion of remaining Salts.
Total solids at 110° C. in parts per 1,000,000	5,427	26·4	$\frac{1}{205}$
Total solids at 400° C. in parts per 1,000,000	4,414	8·4	$\frac{1}{525}$
Organic substances in parts per 1,000,000	1,013	18·4	$\frac{1}{55}$
Silico SiO_2 ,, ,, ,,	243	1	$\frac{1}{243}$
Oxides of iron and alumina in parts per 1,000,000	200	3·2	$\frac{1}{62}$
Lime CaO in parts per 1,000,000 . .	73	2	$\frac{1}{36}$
Magnesia MgO ,, ,, ,, . . .	42·4	1	$\frac{1}{42}$
Chlorine ,, ,, ,, . .	2,583·8	Traces	0
Sulphates SO_3 ,, ,, ,, . .	407	0	0
Hardness ,, ,, ,, . .	24	0·54	$\frac{1}{44}$

In boilers using distilled water, this water in time becomes a fairly concentrated liquid. Organic matter—oils and grease particularly—is present in considerable quantity, and of these only a small quantity is necessary to produce priming. It is, therefore, necessary to avoid this concentration, and continuous blowing-down is consequently applicable in this case also.

Boilers working with distilled water therefore require to be blown-down occasionally, but, owing to the small amount of salt that they contain, it is useless to remove a large quantity of liquid. These boilers are consequently blown-down to the extent of 1 or 2 per cent only, which means that the quantity of saline solution is replaced in the boiler by distilled water. By this method the increase in the quantity of dissolved matter is necessarily limited.

It could not, for example, exceed fifty times the concentration of the distilled water taken from the condenser, in the case of a boiler blown down to the extent of 2 per cent. In the case quoted above, this corresponds to a dry residue of 1·3 grm. per litre, which is certainly not negligible. The water blown down is of no special interest so far as its chemical composition is concerned; but it is hot water which enters the distilling apparatus without loss of its calories.

Even when an evaporator is used, the continuous blowing-down method can be adopted. A certain amount of saline or impure water can be drawn from the boilers and passed into the evaporator; this latter returns it to the boiler after it has been freed of the greater portion of its salts. It will be seen later how the simultaneous use of continuous blowing-down, in conjunction with degassing, allows of the establishment of a complete closed water circuit in a central station using distilled water.

Experience has shown that boilers fed with distilled water as well as those fed with purified water are liable to deterioration due to corrosion of the plates. The interior of the boiler, which is smooth and clean when put to work, becomes covered in places with a thin coating of rust; the small patch of rust increases in size little by little; the rust forms a scale of somewhat spongy nature, and when the boiler is put off work, or frequently even while it is still at work, for various reasons this scale ceases to adhere to the plate and falls from it. In its place there is formed a slight depression, caused by the disappearance of the metal which has entered into combination in forming rust; the depression becomes again rusty, and eats further into the plate by repetition of the process. Some boilers, after having been a certain time at work, have their plates pitted all over so that they recall the battered and dented walls of a village that has been under fire during the war. The strength of the boiler is undermined, and it becomes necessary to renew the damaged plates, or even the whole boiler.

Although the commencement of corrosion does not always become visible, it is nevertheless the cause of serious damage to boilers and shortens their life. Owing to the high first cost of a boiler, an important economy is effected by extending its working life by one or more years. This can be done by preventing corrosion.

The Causes of Corrosion.—What is the origin of corrosion? In the case of boilers using distilled water there can be no doubt. Oxidization of the plate can only be produced by oxygen dissolved in the feed-water and set free in the boiler. When the rate of evaporation is steady and the boiler is in regular work, the dissolved air is released at those portions of the boiler in which the water has not reached the boiling point, or where the circulation is sluggish. At these places bubbles are formed which cling to the surface, and leave their oxygen in combination in the form of rust. There is also the freeing of air-bubbles at the water level when the rate of evaporation is reduced. It is well known that intermittent working is the most destructive cause of all.

The combination that takes place between the oxygen and the iron can be explained in several ways, as may be seen by reference to the work of Newton Friend.* The usually accepted theory is that oxygen, in the presence of water vapour, combines directly with iron according to the following reaction :—

$$2\,Fe + 3\,H_2O + 3\,O = 2\,Fe\,(OH)_3.$$

Treadwell's theory, according to which carbonic gas acts as catalyzer, is also interesting, and leads to the same result :—

$$Fe + CO_2 + H_2O = CO_3\,Fe + H_2$$
$$2\,CO_3Fe + 3\,H_2O + O = 2\,Fe\,(HO)_3 + 2\,CO_2.$$

It is, however, to be noted that even when there is no carbonic acid gas, so far as our methods permit its presence to be detected, rusting occurs. This is disputed by some authorities, but whatever the actual process, it cannot be denied that oxygen is the cause of rust. Numerous electrical theories have been proposed to explain the oxidization of iron. These are not, however, applicable to the case of boilers using distilled water, where electrolytic action is minute and the weakness of the saline solution in the boilers is unfavourable to the production of local currents.

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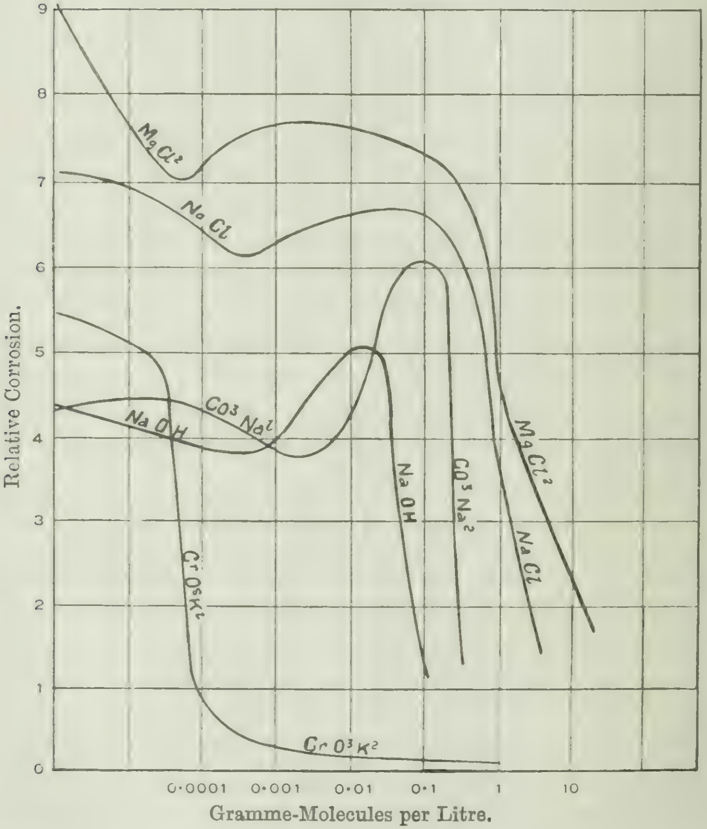
* "The Corrosion of Steel and Iron."

All these theories, taken individually, appear very plausible and might form the subject of a lengthy chemical investigation, into which it is not proposed to enter, as it is of academic interest only.

FIG. 8.—*Relation between Corrosive Power and Concentration for a Number of Solutions.*



If the action of oxygen is obvious and well known in boilers using distilled water, it is not so clear in the case of boilers using purified water, or it may be considered less important on the ground that the concentration of salts, obtained under this system of working, forms the principal factor in the eating away of the plates. This erroneous view depends generally on an incomplete appreciation of the facts ; it has, moreover, been proved that although highly concentrated solutions attack the gun-metal fittings more severely, their action on iron is greatly reduced.

If we examine the corrosive effect of saline solutions, we find that in general it begins by increasing in proportion to the strength of concentration up to a critical point at which it attains a maximum ; the effect then decreases rapidly as the concentration proceeds. The diagram, Fig. 8, shows the relation between corrosive power and concentration for a number of solutions. From these curves it appears that there is a certain critical concentration which must be exceeded in working boilers. In practice, after a few hours' work, a boiler using purified water will have already attained a concentration fully one hundred times the critical amount. Concentrated solutions may, therefore, give rise to a higher boiling point, to priming, and to the deposition of crystals, but corrosion must not be included in the list.

Electrical action may have some influence on the preceding. In fact stray currents may find suitable conductivity in the salt solutions, but boilers are not made of a single piece of plate, and the interruptions caused by the joints tend to localize the effects of the current. Moreover, it appears probable that if currents of sufficiently high voltage existed, they would soon cause serious damage, the only remedy for which would be the adoption of insulation of the boiler. Generally the boiler seatings are very dry and offer no facility for the passage of electric currents. It may happen that galvanic pairs are formed between parts of the boiler which differ in chemical composition or physical nature, but these pairs are generally of but feeble strength and their electrolytic effect would be slight and confined to small areas.

There is still the question of electrolytic dissociation. This occurs much more easily in a dilute than in a concentrated solution, which confirms the previous statement ; in general it is of much less importance than the phenomena to which corrosion is attributed.

Hydrolysis may have much more important effects. A particularly important case, and the best known, is that of magnesium chloride, which gives rise to the production of hydrochloric acid, and is liable to cause indefinite corrosion. Magnesium chloride in the presence of water may be decomposed into magnesia and hydrochloric acid which attacks the plates vigorously.

$$MgCl_2 + H_2O = MgO + 2\,HCl.$$

Fortunately this salt only occurs occasionally, and is sufficiently well known for special care to be taken where the feed-water contains magnesium chloride. Acids attack the plates, but, apart from the case just mentioned, the only acid found in boilers is the carbonic acid introduced in the feed-water. Carbonic acid alone has only feeble action on iron ; in the laboratory a cold concentrated solution of the gas produces only a few bubbles of hydrogen on a piece of iron immersed in the solution. If, however, oxygen is present, the metal is attacked much more rapidly, because the ferrous carbonate formed decomposes into rust and carbonic acid which recommences the action. In this case also it is oxygen that produces the corrosion.

Oxygen comes into play still further when the water contains salts capable of combining with oxygen and forming unstable oxygen-compounds which can part with their oxygen to form other oxides. Among these salts some, particularly certain oxychlorides, are known and have been separated ; but the hypothesis, that certain oxy-salts that have not yet been separated may be present, affords an explanation of the rapid eating away of iron by sodium chloride in the presence of air, whereas solutions of the same strength, absolutely free from oxygen, can be kept in contact with the metal without effecting any change whatever.

Thus it appears that it is the solution of atmospheric oxygen in water that is the chief cause of corrosion, whether the feed is distilled water or purified water. This is supported by the fact that corrosion is often more serious in boilers using distilled water, in which dissolved oxygen can be the only agent, than in boilers using purified water.

The remedy therefore appears to be very simple, namely, the elimination of the dissolved oxygen.

Oxygen in Solution in the Feed. — Atmospheric air (and therefore the oxygen that it contains) dissolves in water almost instantaneously up to the point of saturation for the particular temperature and pressure. The solubility of air in water is proportional to the pressure, and inversely proportional to the temperature; it follows Henry's law which, though approximate, is very nearly true for the case of air mixed with a gas that is not very soluble in water. Each of these gases dissolves in proportion to its share in the pressure, as though alone; thus air contains four volumes of nitrogen to one volume of oxygen; the share due to the nitrogen is 0·8 and that due to the oxygen is 0·2.

At ordinary temperatures and pressures 18 cm^3 of pure nitrogen and 35 cm^3 of pure oxygen form saturated solutions with 1 litre of water. The quantities of each dissolved from air are therefore:

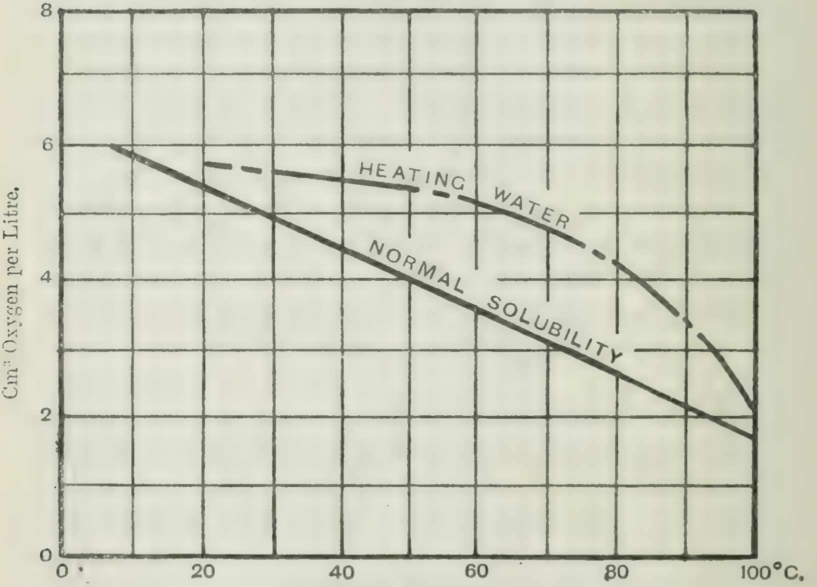
$$\text{Nitrogen}: 0{\cdot}8 \times 18 = 14{\cdot}4 \text{ cm}^3.$$
$$\text{Oxygen}: 0{\cdot}2 \times 35 = 7{\cdot}0 \text{ cm}^3.$$

The air dissolved in water will therefore contain, roughly, 33 per cent of oxygen, and be twice as rich in this gas as atmospheric air. Laboratory tests have shown that the quantity of oxygen dissolved in water varies slightly with the nature of the water; distilled water absorbs more than fresh water, and soft water more than hard water. Distilled water absorbs 7·8 cm^3 per litre at 20° C., 2·1 cm^3 at 100° C. The water supply of Paris contains 6·06 cm^3 per litre at 20° C., 4·3 at 55° C. and 2 cm^3 at 100° C.

When water is heated, supersaturation occurs. Nothing is given off up to a temperature of 75° C. at which bubbles begin to form and rise until boiling takes place, when the bubbles are disengaged continuously. Air is only driven off continuously when the water is agitated incessantly from the commencement. When water that has been boiled is cooled, the inverse takes place; a litre of water absorbs, for instance, 2·3 cm^3 at 44° C. and 3 cm^3 at 20° C. If the water is agitated in air the false state of equilibrium is disturbed, and the water becomes saturated up to 6 cm^3 of oxygen, Fig. 9. The straight line is the normal solubility obtained when the water is continuously agitated, and the curved line gives the contents at different temperatures without agitation.

Thus conditions of unstable equilibrium may occur which cannot exist when the liquid is agitated, and in every case equilibrium is

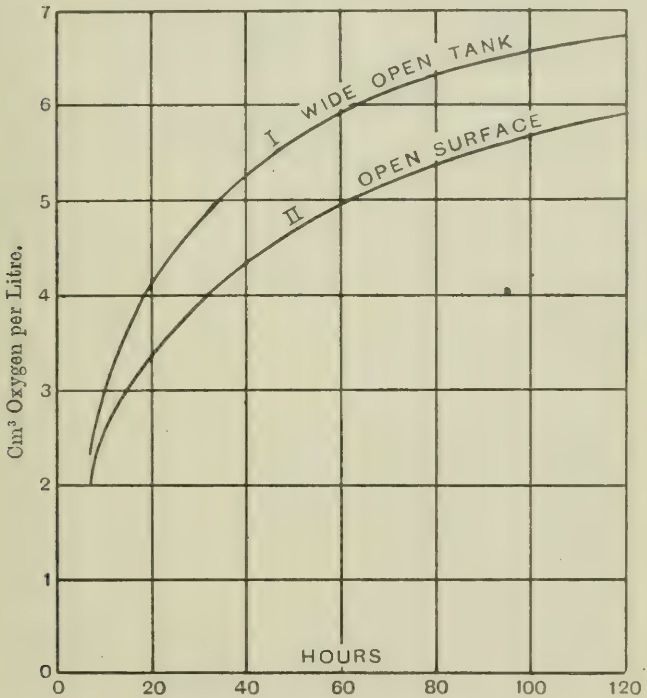
FIG. 9.



Solubility of Air in Water.

obtained for the particular temperature and pressure considered. If water is contained in a deep vessel, a sample taken at any moment from the surface contains the same percentage of gases as a sample taken from below; the diffusion of oxygen in water is extremely rapid. The area of the surface exposed to the air of water that has been boiled has an influence on the rate of absorption. Thus the water resulting from the condensation of the vapour in the air contains 4 cm^3 of oxygen per litre at 60° C. The same quantity of water of condensation exposing only a small surface to the air contains only 3 cm^3 of oxygen per litre at the same temperature. According to Hohn, the surface affects the rate of absorption of the oxygen, as is shown in curves I and II obtained with a surface II (seven times that of the surface I), Fig. 10.

FIG. 10.

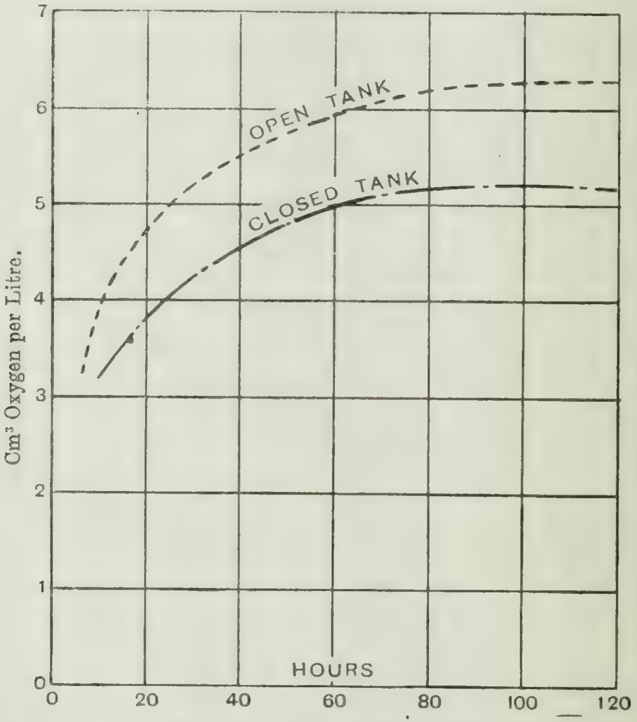


Influence of Surface upon Solubility.

The possibility of changing the air also has an influence. If the reservoir is closed, but not hermetically, the oxygen is absorbed less rapidly than it could be from the open air, in which case saturation would be almost instantaneous, owing to the contact and the movement of the water. Hohn gives the following curves, Fig. 11.

Method of Obtaining the Oxygen Content.—All the methods of analysis that have enabled the data given above to be obtained and the determination of complete absence of gas have been made by Max Müller's method in which certain modifications have been made.

FIG. 11.



Influence of Velocity of Contact.

General Description.—The water is collected in a vessel protected from the air. Manganese sulphate is dissolved in it, and by the addition of sodium hydrate the hydrate of manganese monoxide is precipitated; this absorbs the oxygen contained in the water, transforming it into an oxy-salt and the dioxide. This is treated with hydrochloric acid, which reacts on the oxides of manganese, giving off a quantity of chlorine equivalent to the quantity of oxygen absorbed. The freed sodium chloride reacts on potassium iodide and sets free the equivalent of iodine. Titration by hyposulphite of soda gives the quantity of iodine and enables the equivalent amount of oxygen to be determined.

Method of Operation.—It is important, when it is a question of determining the quantity of oxygen in water containing but little, to avoid any contact of this water with the air. For this it is only necessary to put a small quantity of paraffin at the bottom of the 2-litre flask in which the water will be received and to dip the tube bringing the water below its surface. Thus, during the whole operation, an insulating covering will be provided over the surface of the water.

After the water has been collected in the flat-bottomed 2-litre flask, 1 gramme of sulphate of manganese is added and the neck is immediately closed with a rubber stopper fitted with a funnel having a stop-cock and a glass tube connected by a rubber tube to another glass tube of larger diameter, carried on a stand.

On the principle of connected vessels, it is possible, by raising or lowering the tube, to change the pressure in the flask and to cause it to suck in liquid contained in the funnel fitted with the stop-cock. It is necessary that there should be no air bubbles in the apparatus, and this is easily attained after a little practice. When the sulphate of manganese has been dissolved, 5 cm^3 of sodium hydrate in solution is introduced through the funnel of the stop-cock and the flask is shaken. A dirty white precipitate is formed, turning more or less yellow, according to the quantity of oxygen contained in the water. At the end of a quarter of an hour the absorption of oxygen is complete.

The next operation is to introduce 2 cm^3 of solution of 50 per cent of iodide of potassium free from iodate through the funnel fitted with the stop-cock, and then to add 20 cm^3 of concentrated hydrochloric acid. The flask is shaken until the precipitate has dissolved ; the liquid takes a yellow colour, darker as the quantity of iodide freed is greater. The flask is then emptied into a bath and the iodine determined by titration.

The most practical method consists in preparing a standard solution of iodine containing 22·74 grammes per litre; that is, of such strength that a cubic centimetre corresponds to a cubic centimetre of oxygen. A solution of hyposulphite is prepared of such strength that it corresponds practically volume for volume with the solution of iodine. The number N of cubic centimetres of this solution corresponding to 20 cm^3 of iodine is determined experimentally. To the solution of iodine contained in the bath N cm^3 of hyposulphite is added, and then a small amount of starch, and the iodine is titrated again until a permanent blue colour is obtained. Let N be the number of cubic centimetres of iodine added. The iodine contained in the test will correspond to 20 N cm^3 of liquid titrated, and the test will consequently contain $20 - N$ cm^3 of oxygen.

This method is simple, rapid and exact. It is delicate in application in the case in which the water contains traces only of oxygen, on account of the avidity of hydrate of manganese, which absorbs instantaneously the oxygen of any bubble of air coming into contact with the water. It is necessary to ascertain that all the reagents are pure, and particularly to make a blank test of the hydrochloric acid on iodide of potassium.

Removal of the Gases.—The elimination of the oxygen dissolved in water may be effected either by physical methods, or by chemical methods, or by the two combined. The principal physical methods to be mentioned are: agitation of the water; the action of temperature; and the action of vacuum. These three methods may be used either separately, or in the majority of cases in combination, in order to obtain the elimination of the gases from the water. Of the chemical methods the only one to be considered is the action of highly oxidizable iron, which absorbs the oxygen from the water before entering the boiler.

Removal of the Gases by Physical Methods.—Agitation of the water is used in various appliances in the form of fine spraying or circulation through channels of varying section, or again by the action of points and roughnesses on the current of water. These can only have the effect of preventing supersaturation at the particular temperature and pressure. Consequently they can have no effect beyond that of the action of temperature combined with a vacuum. Raising the temperature diminishes the solubility of the gases. But even if the temperature of the water is raised to 100° C., the solubility cannot be neglected; solutions containing about 2 cm^3 per litre can be obtained at atmospheric pressure. The operation of heating, however, produces by itself a great improvement in the condition of the water entering the boiler, for there is no longer such a large release of air when the feed-water comes into contact with the water at a higher temperature in the boiler.

A vacuum would give better results still if it could be carried out at a very high temperature, the solubility of air being proportional to the pressure, according to Henry's law, as has been already stated. But the vacuum, particularly when the water is hot and attains 80° C., cannot be very high, for otherwise the water would boil. At 80° C. it is not possible to fall below about 0·5 atmosphere, and at 60° C. more than 0·8 atmosphere.

If the three methods mentioned are used in combination, that is to say, if the water is submitted to the combined action of temperature and a vacuum, and supersaturation is prevented by mechanical action, the results shown in the following diagram will be obtained, Fig. 12 (page 316).

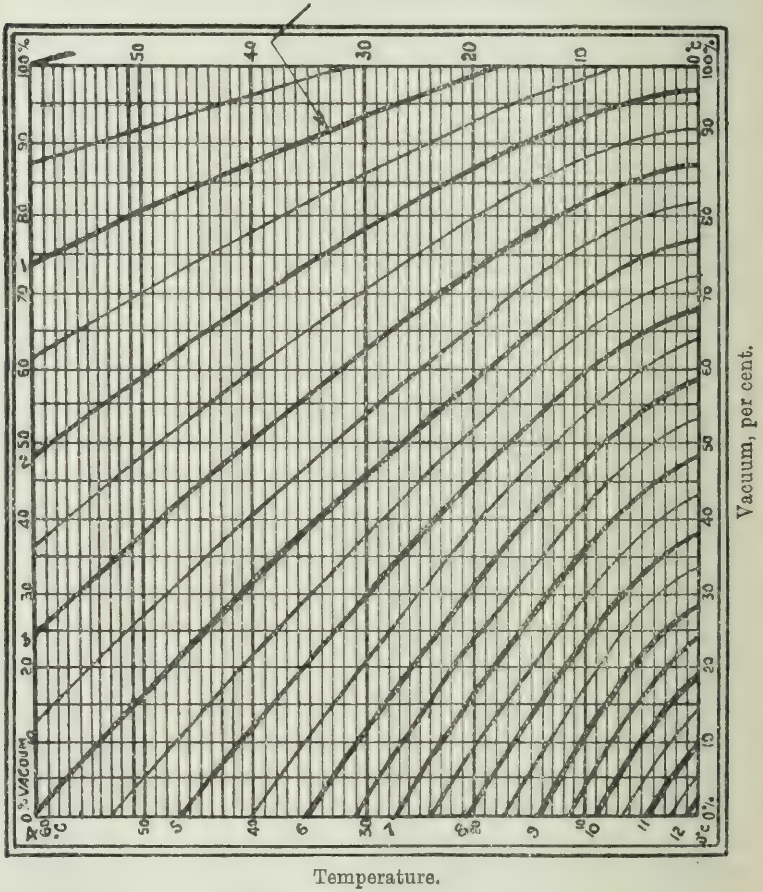
This curve has been prepared and published by a large German company making an apparatus, which uses the three methods simultaneously. It appears to be, if examined carefully, favourable to the use of these methods. Notwithstanding this, the firm is obliged to state: "There are still some milligrammes of oxygen that cannot be removed by a very high vacuum and by reheating the feed-water, but they have no aggressive action; the danger arises alone from a rich supply of oxygen."

The action of iron on dissolved air in the feed-water enables even the last traces of oxygen to be removed and water to be obtained absolutely free from oxygen. This proves that even the "last

FIG. 12.

Absorption of Oxygen in Water at Different Temperatures and Vacua.

Milligrammes of Oxygen per Litre.



milligrammes" of oxygen are capable of causing rust and corrosion. Nevertheless, the physical operation of removing gases gives very satisfactory results, because it diminishes the percentage of oxygen in the feed-water and slows down the corrosion. But the use of a vacuum appears very difficult in appliances of large sizes, as it requires a very keen supervision at all points ; and when leakage occurs, there is a churning effect produced in the water by the entry of the external air which, notwithstanding the decrease of pressure caused by the air temperature, produces the opposite result to that which is desired. A leakage of this kind is hard to locate, and for this reason it is always possible that such leakages may exist.

Numerous appliances have been constructed in England, America, and in Germany, for effecting physical removal of the gases. The principal ones in use are the following :—

(*A*) *Thermal and Mechanical Removal of Gases.*—All feed reheaters open to the air produce a removal of gases in so far as they diminish the solubility of air in water. Those in which the water flows in contact with steam in reservoirs that are not tight are those which best perform the operation of the removal of gases by heat alone. Those that reheat the water in closed receptacles, e.g., in tubular economisers, remove the gases to a great extent from the water, but introduce gases into the boiler when it becomes necessary that the gases that have been removed are allowed to escape. Among these appliances those most in use are superheaters by Cochrane and Webster, and Weir, etc.

The apparatus of Chevalet, by its construction as a superheater with plate surfaces, differs slightly from the preceding appliances, and in this the steam bubbles through the water. All the " heating nozzles " of apparatus in which water is subjected to mechanical action and to the action of heat come within this class.

These appliances are accessories in the operation of removing the gases ; there is one which can lay claim to the production of a better result, and that is the Aerex apparatus, in which the water loses its gases in being divided over two rubbing surfaces. The gases reunite and are removed by a valve when they have attained a sufficient quantity.

The Siegmon Schmitt gas remover adopts a principle similar to that of partitions with baffles. The two appliances are placed on the delivery; they have more effect when the water is hot, but, on the other hand, they suffer some reduction in their action in consequence of the pressure on the feed-water, the pressure assisting the solution of the gases.

To eliminate gases by heat the firm of Balke, in Germany, combines an arrangement for reheating the water by steam with extraction of the gases evolved in an appliance in which the water is subject to forced circulation, and the air removed is exhausted by an arrangement of valves at the top of the apparatus. The water freed from gas is kept in contact with a layer of inert gas at the lower part of the apparatus. This somewhat complicated installation does not appear to have met with much success.

(*B*) *Vacuum Appliances for Removing Gases.*—Some firms have constructed apparatus using a vacuum for removing gases from water. Most of these are schemes of apparatus which have but rarely been developed into practical shape; such are the arrangements of Meihof worked by Halvor Breda and the Griesheim Elektron Lauta. The "Deutsche Sanitäts Werke" of Frankfort have constructed apparatus which is of considerable interest.

The Meihof, applied at Swinemunde, acts by passing the water from which the gases are to be removed through a siphon arrangement. If the branches of the siphon are of sufficient length, a vacuum is produced at the upper part, due to the suction in the descending branch. This vacuum causes the release of gases dissolved in the water at the top of the siphon. The principle is very simple and requires no mechanical arrangement; the water from which the gas has been removed is returned to the level of the water supply. The vacuum obtained in such an arrangement is not very high; it is limited by the destruction of the vacuum in the siphon by accumulation of gases. When these gases are removed, the vacuum disappears; this removal is produced by valves arranged on the particular part of the siphon operated at the time when the water returns for priming the siphon. In the apparatus constructed at Swinemunde for the removal of gases, the maximum vacuum corresponded to 5 metres (16 feet) of water, which is not a high degree of vacuum.

The apparatus of the Griesheim Elektron Lauta, is of very simple construction, consisting of a reservoir in which the temperature of the water is raised by means of steam. A vacuum is created by the heated water and the gases that accumulate are extracted by means of a pump.

The apparatus made by the Deutsche Sanitäts Werke is largely in use and is of very original design. In principle it consists of a tube with numerous contractions, to the upper part of which a vacuum pump is attached. At the base of this tube, which is immersed in the water from which the gases are to be removed, there is an adjustable air suction-pipe. Doubtless this air passes over an oxidizable filter in order that its oxygen may be removed from it. As a result of the vacuum, the water and air that have been filtered rise in this column ; there is a vigorous shaking of the liquid due to the passage of the gas and to the contractions. This violent movement in conjunction with the vacuum causes the release of the gases dissolved in the water, and these gases are drawn into the upper part of the apparatus by the vacuum pump. It is certain that different conditions prevent a high vacuum from being obtained, in particular the shaking by use of gases and the height of the apparatus, which is far from attaining the dimensions required by the barometer. For this reason it is said " that there are still a few milligrammes of oxygen remaining in the water " ; nevertheless, this apparatus certainly removes the oxygen to a great extent from the water that has passed through it, and it contains at its maximum the percentage corresponding to saturation at the pressure obtained in the column and at the temperature of the water. This apparatus appears to be in wide use.

Chemical Removal of Gases.—All chemical methods of removal of gases in actual use are based on the same principle. They consist in causing the water that it is desired to free from oxygen to pass over iron. If the iron has a sufficiently large surface, if its chemical composition is carefully selected in order that it may be very easily oxidizable, and, lastly, if the water is circulated sufficiently slowly for the oxidizing action to be complete, the chemical removal of the gases enables all the oxygen contained in the water to be eliminated; in fact, the oxygen may be combined with iron in the presence of water so as to give different hydrates, of which the richest is rust:

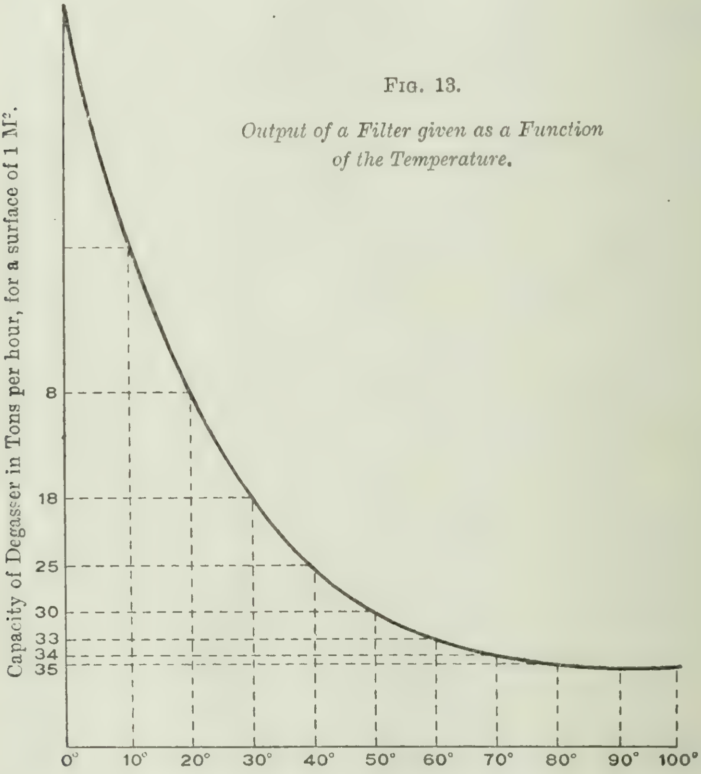


FIG. 13.

Output of a Filter given as a Function of the Temperature.

Temperature, Centigrade.

$$2\,Fe + 3\,O + 3\,H_2O = 2\,Fe\,(OH)_3.$$

This reaction is practically quantitative; it requires more or less time according to the temperature at which it takes place, but it can always, whatever be the temperature, effect a sufficiently complete removal of the gases, if the iron is largely in excess in regard to the oxygen, so that nothing but minute traces of gases remain in the water.

For the same quantity of iron turnings, the quantity of water from which the gases are removed is proportional to the speed of the reaction, and consequently proportional to the temperature. The output of a filter is given as a function of the temperature by the following curve, Fig. 13. If the velocity is caused to vary in a given filter, it will be seen that it cannot yield more than a certain limited quantity if it is desired that the removal of the gases should be efficient.

The output is also proportional to the quantity of turnings in contact with the water; this quantity, moreover, cannot be increased indefinitely because the size of the apparatus would require to be sufficiently reduced so as not to be an obstacle to its introduction into a boiler room.

Another factor intervenes in the working of these appliances; it is the facility with which the metal used becomes oxidized. Practice shows that very impure iron rusts very rapidly. Laboratory experiments have enabled the Author to find a catalytic agent of great importance, namely, manganese. The presence of manganese hastens the oxidization of the metal; nevertheless, if this action shows itself in the case of small percentages corresponding to the manganese steels, it is not so well marked in the case of higher percentages. A metal which is rich in manganese is cast-iron. and cast-iron is much less oxidizable than steel. The physical and chemical composition of the metal has therefore a great influence.

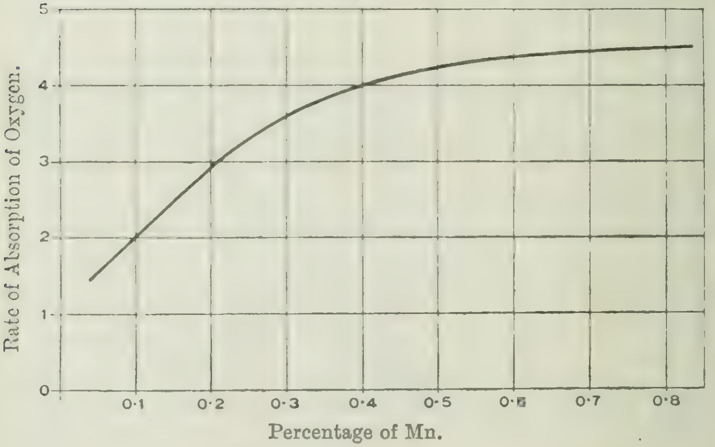
The catalytic action of manganese may be represented by the following curve, the metals under consideration being very closely allied in composition and physical properties, and differing only by their percentage of manganese, Fig. 14 (page 322).

To sum up, it is seen that from the chemical point of view, the removal of gases by iron depends: on the surface of the metal, on the temperature of the water, on the speed at which it passes over the metal, and, finally, on the composition of the iron.

To obtain a maximum surface with a certain quantity of iron it must be used in a finely subdivided form, preferably in turnings. There is then a physical removal of the gases at atmospheric pressure which reduces the gases in the water to the point of saturation for air at the temperature and under the pressure in question. This action is of great advantage, and reduces the amount of turnings required to a considerable extent.

FIG. 14.—*Velocity of Absorption of Oxygen for Degasser.*

The Rates of Absorption of Oxygen are expressed in equal proportions for the same velocity of flow of water through the Apparatus.



In commercial appliances, the following phenomenon may occur: When the coating of rust becomes very thick, contact of oxygen with the iron is no longer good, and the chemical removal of the gases may be considerably slower. Notwithstanding this, under the worst conditions, a water leaving such apparatus may be found to contain less than 0·5 cm^3 of oxygen per litre. There are some other appliances working on the same principle as the German degassers constructed by the firms of Hulsmeyer and Seiffert, and an American apparatus due to Professor W. H. Walker.

The Hulsmeyer apparatus consists of a column of iron turnings distributed in baskets of perforated sheet-iron, which allow it to be distributed equally. This column of iron turnings ends in a filter which retains any particles of iron-oxide that may become detached. At the top of the apparatus there is fitted an automatic float-operated valve for the relief of the gases released by physical action. The water circulates from the bottom to the top of this very simple apparatus. The Hulsmeyer apparatus may be included as either falling under the suction type or the pressure type.

The Seiffert apparatus is constructed on the same principle, but comprises a reheater. Starting with the fact that heat encourages physical and chemical removal of the gases, Seiffert filled the tubes with a tubular superheater filled with iron shavings. The apparatus is of the most simple kind, and is, perhaps, very effective, but the replacement of the iron shavings in the tube cannot be a very easy matter.

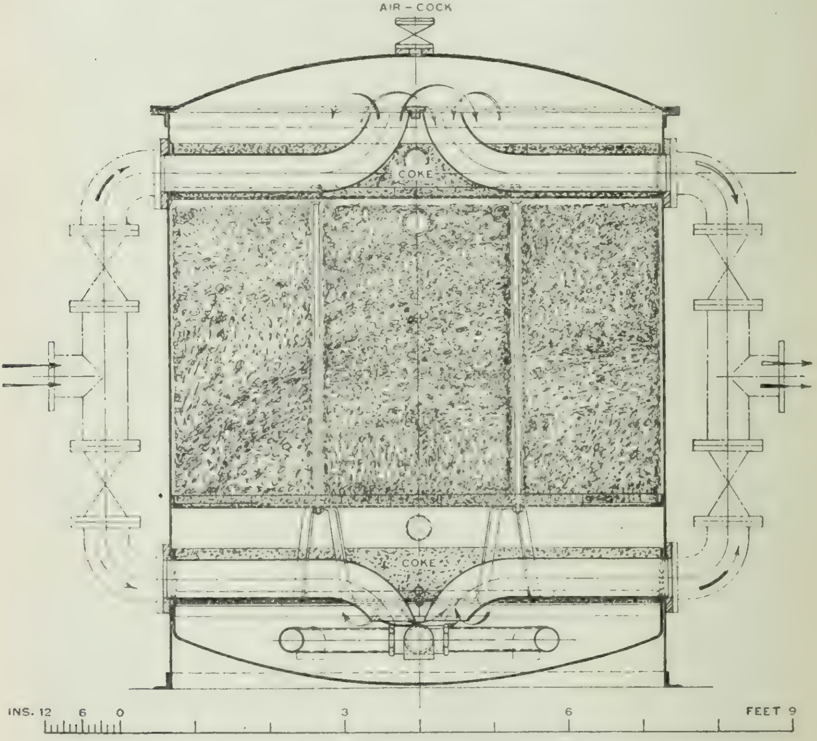
Prof. W. H. Walker proposes an apparatus for removing the gases from hot water, consisting of a receptacle filled with perforated plates one above the other. This apparatus he styles a "deactivator." The only point that appears to have been overlooked is the absence of a valve for allowing the gases released in the apparatus by its mechanical action under the influence of the circulation of water between the plates.

To avoid the slowing of the oxidizing process by the rust deposit on the iron, the Kestner Co. has designed an apparatus based on the following: If an apparatus for removing gases by means of iron is left with the iron rusty, it is found that after a day of rest, the rust, which was red, has become an oxide of a greenish-black colour. This transformation is due to the reduction of the ferric hydrate under the influence of the iron; a saline hydrate of the oxide and a ferrous oxide is obtained. The following is the reaction:

$$2\ Fe\,(OH)_3 + Fe + 2\ H_2O = Fe_3\,(OH)_8 + 2\ H.$$
$$2\ Fe\,(OH)_3 + Fe = 3\ Fe\,(OH)_2.$$

This reaction takes place in the middle of the reducing agent, that is, in the presence of iron and in the absence of oxygen. The saline oxy-hydrate formed is easily removed from the iron by washing, and moreover it is capable of further absorbing oxygen in becoming ferric-hydrate. In order that the apparatus for removing the gases should retain its working speed, it is necessary that it should be put alternately in and out of circuit, the two appliances in work retaining the power of the iron for absorption until the latter has been completely oxidized. The Kestner apparatus, Fig. 15, is based upon this principle, and consists of a column of turnings of sufficient quantity for half only to be in action, and to allow that the water shall have lost these gases on arriving at

FIG. 15.—*Arrangement of Degasser* (Kestner).



half the height. The second portion of the iron being in contact with this deoxidizing agent gives rise to rapid reduction, its rust changing to the condition of a suboxide. At the end of the day, the direction of flow is reversed. The water then passes over the iron, which has become a suboxide, which is then changed to a peroxide, and arrives free from gases on the surface (rusted the day before) which in turn is reduced. Thus, each half of the apparatus works alternately by inversion of the direction of circulation of the water, and the removal of the gases becomes continuous and absolutely regular.

The Kestner apparatus consists of a column of iron turnings placed between two filters with an intake and outlet for the water at each end of the apparatus, in such manner that the direction of flow of the water can be inverted at regular intervals. Like the other filters using iron turnings, it may claim completely to eliminate the oxygen from the water with greater certainty. The consumption of turnings and the speed of the absorption of oxygen are approximately regular, and the arrangement for allowing steam to be admitted at the base of the apparatus allows it to be cleaned by blowing steam through and removing any rust which may become detached from the iron on which it was produced.

The consumption of iron turnings in the apparatus for removing gases is very small ; according to the percentage of oxygen contained in the water, it varies from one to three grammes per cubic metre (per ton) of water which reduces the cost of the removal of gases to a negligible figure. The iron consumed in the gas-removing apparatus corresponds to the same weight of boiler-plate which has been saved from destruction, and the difference in first cost between the two materials destroyed forms a very great saving.

Whatever may be the method employed for removing the gases, it involves a circuit of water closed from atmospheric contact if it is to give a large output. The water which has been freed from gas can become saturated very rapidly by air. It is, therefore, advisable that the tanks in which the water may be retained should be as well enclosed as possible, and that on the whole of the pipe system there should be a small positive pressure. A head of a few centimetres of water is sufficient to prevent the entry of air which might happen accidentally through bad joints or accidental circumstances. In such a pipe system the only place at which the entry of air may be possible is the condenser in which the vacuum is produced. The tightness of the condenser should, therefore, be very carefully tested. Moreover, to avoid the effect due to any air entering by accident, which may always occur, it is essential that the water should pass through the gas remover immediately before entering the boiler, even though this water should result from condensation, and though it may only contain a small quantity of oxygen. Iron turnings are only consumed according to the percentage of oxygen in the water, and water free from gas does not change this ; consequently, it does not necessitate expense by being passed through the degasser. The degasser so placed protects the boiler and the economiser from any attack by the gases, and acts as a doorkeeper to prevent the entrance of anything undesirable.

The study of continuous blowing down, on the one hand, and that of degassing on the other hand, have led to the conception of a complete circulation system for a central station using distilled water. The main guiding principles of this idea are as follows :—

The ability to use any one boiler as a distilling apparatus, and to feed the other boilers with the water distilled in this boiler.

The blowing down of a large quantity of water from the boiler that is performing the function of distilling ; the blowing off of only a small quantity of water from the boilers using distilled water, and the conveying into the distilling boiler of the water so blown down.

The protecting of the condensed water from all contact with the air by means of a closed circuit ; the degassing of the condensed water before its passage through the economisers and the boilers.

From the moment at which the water is degassed the keeping of it enclosed so that no entry of air is possible.

The degassing of the water to be purified before it passes into the distilling apparatus.

There should be no point on the circuit of the purified water in common with any on the circuit of the distilled water.

The only appliances that may be common to the boilers are the blow-off manifolds and the steam mains.

It will be seen that the scheme of this system of water circulation purification and degassing rests on a very broad basis, and that the distilling apparatus may equally well be an evaporator or a boiler. Each has its respective advantages.

For a water circulating, purifying and degassing plant the following system is proposed, Fig. 16 (page 328) :—

One of the boilers is to evaporate the purified water coming from the purifier. It will supply steam that will go with that generated by the other two boilers to the steam main. The steam will pass through the turbines, it will be condensed and it will re-enter the boilers as distilled water after it has passed through the degassing apparatus.

All the boilers are to be blown down, the boilers using distilled water to the extent of, say, 2½ per cent, and that performing the distillation of the water to the amount of, say, 10 per cent, and all of these amounts that have been blown down are to pass collectively through the purifier in which they will be subjected to the same treatment as the ordinary "make-up" feed-water, and the impurity is to be measured by the testing apparatus. The purified water is to be returned to the particular boiler performing the distilling, after it has passed through a special degassing appliance.

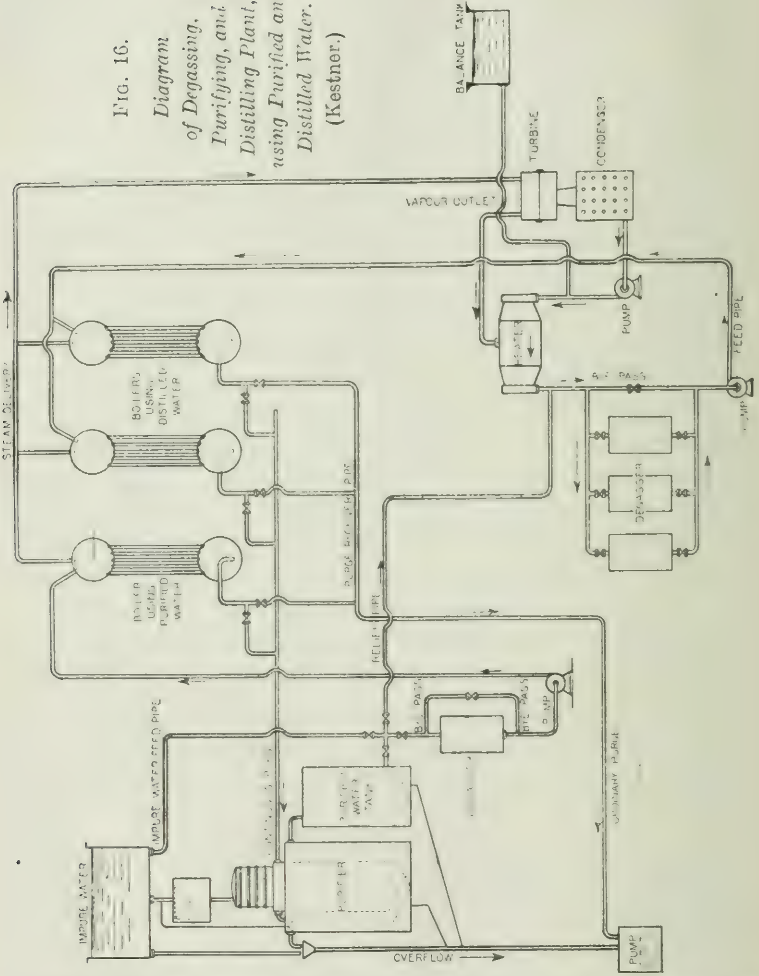
The boiler containing the water that is to be purified will thus furnish the supply to the boilers working with distilled water in the form of steam ; there will be no common portion between the circuit of the purified water and that of the distilled water. It will merely be necessary to provide an overflow reservoir to enable any excess of purified water to be reintroduced into the circuit if such excess should be produced.

All the boilers can be fed either with purified water or with distilled water, which enables any desired boiler to be used for the work of distilling.

Such a circuit will ensure that a central station will have the best possible thermal balance sheet, and moreover a longer life for the

Fig. 16.

Diagram of Degassing, Purifying, and Distilling Plant, using Purified and Distilled Water. (Kestner.)



Scheme for the purification of make-up water by continuous blow-down and degassing of all water before discharge to boilers. One boiler operates on purified make-up water; the remainder using distilled water only.

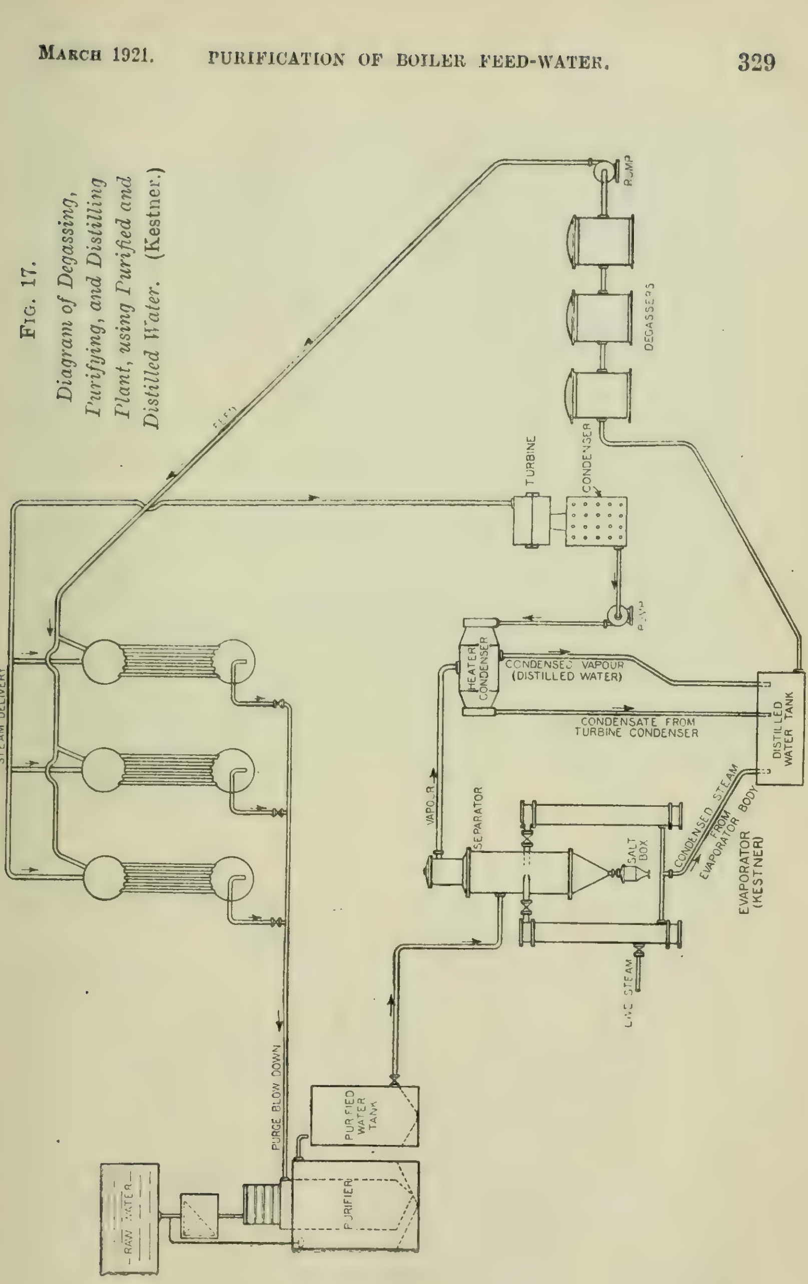


FIG. 17.

Diagram of Degassing, Purifying, and Distilling Plant, using Purified and Distilled Water. (Kestner.)

boilers, which the process protects from formation of scale and corrosion.

It is obvious that a similar scheme can be arranged for the distillation by means of an evaporator, which under certain circumstances offers advantages. Such an arrangement is illustrated in Fig. 17.

The Paper is illustrated by 17 Figs. in the letterpress.

Discussion.

The PRESIDENT said that, in view of the applause with which the Paper had been greeted, it was hardly necessary to propose a formal vote of thanks, and asked the Author to accept the thanks of the Meeting. The Paper brought very forcibly to his mind the necessity of an *entente* between Mechanical Engineers and Chemists. Chemists indicated what was wanted in regard to various operations, and it then remained for the mechanical engineer to devise the apparatus whereby those operations could be carried out.

The Resolution of Thanks was then put and carried with acclamation.

Sir WILLIAM POPE, K.B.E., F.R.S. (President of the Society of Chemical Industry), said the pleasant duty fell to him, on behalf of the Society of Chemical Industry, to welcome the Author to the Joint Meeting of their two great Societies. The profession of chemical engineering had now become a well established one, and amongst its numerous members there were, as in every other profession, a few who stood out in that their work always bore the stamp of genius. They were accustomed to look for that mark of originality in everything the Author did. They had seen it in the past; they had discerned it in his Paper that evening, and they looked forward to seeing it again for many long years to come in his future work. Their recognition of the Author as an artist in a great profession was evidenced by the fact that the Society of

Chemical Industry had conferred upon him the highest honour in their gift, namely, the Medal of the Society, and he was the only Frenchman who had received that award up to the present.

The Author had always been a great advocate of the necessity for closer co-operation between his own nation and this country, and it was because of his belief in that necessity that he had put himself to the inconvenience of coming to London to address the Joint Meeting of the Institutions. But he thought on the present occasion something more than that might be said. Captain Sankey had remarked on the necessity for more mutual effort between the chemist and the engineer, and in the present Joint Meeting there was to be seen, he hoped, the inauguration of a period of closer co-operation between the two great subjects with which they dealt. The alleviation of many of the troubles from which the world was now suffering depended upon progress in engineering, in chemistry, and in chemical engineering. It was no part of his task on the present occasion to open a technical discussion on the subject before the Meeting. There were many present who had a very wide practical acquaintance with the subject of the Paper, and he would therefore leave the discussion of the important points which had been raised to those who were better able to deal with them.

Professor J. W. HINCHLEY, in opening the discussion, said the Author had been labouring at the subject a long time, and he believed he had succeeded in evolving a practical solution to a very difficult problem, namely, that of freeing water and steam raised from it from the corrosive oxygen and carbon dioxide usually present. The fact that ferric hydrate in contact with iron was slowly reduced to the ferrous state, and was again capable of performing the function of an oxidizer, was a remarkable chemical fact to be used in solving the practical problem. The absence of corrosion in the boiler would be not less important than its absence in other parts of the plant through the freedom from oxygen of the steam. The presence of air in steam was one of the bugbears of the chemical engineer. He did not believe the mechanical engineer worried about it, but he certainly had great evidence of it in the damage that was done to condenser tubes and other parts of his plant. He was very interested in the fact that the Author had found that cast-iron containing manganese was an extremely active rusting agent. He believed cold blast cast-iron liners were usually stated to be used in ordinary cylinders of steam-engines, but there was little doubt that many of those liners were cast from metal made in an ordinary cupola by the addition of steel containing appreciable amounts of manganese, and it was quite possible that much of the corrosion that was obtained in those cylinders might be due to the oxygen in the steam and the presence of manganese in the cast-iron. He believed manganese was a notorious agent for producing segregation, especially of sulphur as manganese sulphide. He would like to know from the Author whether he determined the percentage of sulphur at the same time that he determined the manganese, and whether the segregation of manganese had anything to do with those characteristic properties which he found, or whether it was merely manganese in solution in the cast-iron or equally distributed through it. He would also like the Author to say whether he found that the amount of graphitic carbon in the grey cast-iron which he used had any great influence.

Mr. ARTHUR SPYER said it was difficult for him to criticize the Paper, because he was so absolutely in agreement with the theories the Author had enunciated, especially in regard to the necessity of degassing feed-water. The Author had pointed out that carbonic acid gas and oxygen, when they were present in the feed-water, resulted in a recuperative action, because ferrous carbonate was first formed, then in the presence of oxygen this was transformed into ferric carbonate, which, being a very unstable body, again resolved itself into oxide of iron and carbonic acid gas, so that, if the carbonic acid gas was not got rid of, the action was continuous and recurrent. The Author had spoken at great length on the so-called chemical method of degassing, and he was very much interested to hear the propositions he made in reference to the use of what might be called the steel-shaving method, because until quite recently the results of degassing with that method of treatment had not been altogether consistent; in fact, in many cases it was known they had been unsatisfactory. There seemed to be several indications, however, that with the modifications suggested by the Author those difficulties might be overcome.

Another point raised was the use of evaporators. The vapour produced in ordinary evaporators frequently contained carbonic acid gas, oxygen, and traces of copper salts. If these substances obtained access to the boiler-water, they reproduced the gas difficulty and hence the necessity of getting rid of the gases. The most agreeable waters for drinking purposes were usually impregnated with carbonic acid and oxygen, and whilst exceedingly pleasant to drink, they were exceedingly bad for boilers.

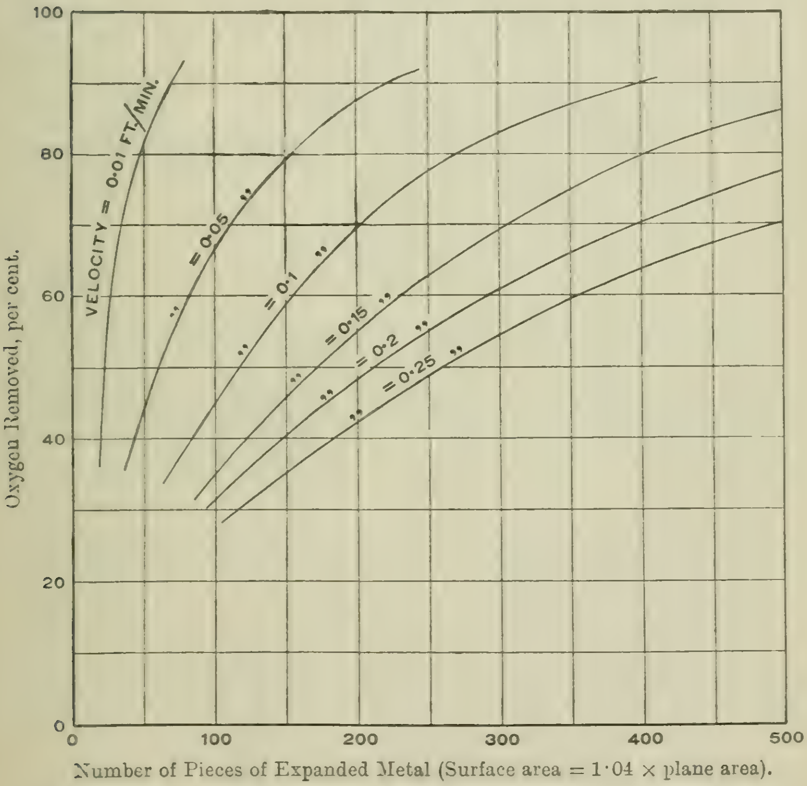
With regard to the suggested method of a continuous blowing out, he did not wish to be hypercritical in any way, but in a well-managed station at the present day, with the methods which were adopted of getting rid of solid matter in the feed-water, the amount of blowing out from the boilers should be very small. It was rather doubtful whether it would pay commercially to install somewhat costly apparatus as described in the Paper, unless very definite evidence were forthcoming of the gain to be obtained, because, after all, engineers unfortunately had to consider whether a particular apparatus paid or not.

In dealing with the subject of corrosion, the Author had referred to galvanic action. In his own experience he had never yet seen a case in which he was convinced that galvanic action of itself had been the cause of corrosion. The wear of the zinc blocks which were frequently fitted in boilers, was more probably due to ordinary oxidation than to galvanic action. He was absolutely in agreement with the Author with regard to the beneficial effects of heating the feed-water before subjecting it to the discharge pressure; it undoubtedly helped to get rid of gas, and facilitated the action on the water of any chemicals which might be introduced. It reduced the solubility of the salts at high temperature, and therefore enabled a great proportion of the salts to be got rid of before they went into the boiler. It should be the object of engineers and chemists first of all to take care that no air got into the feed-water; in the second place, to take all possible steps to prevent the access of air to the feed-water subsequently, and, thirdly, to heat it as much as possible, so that any gases which were present might be eliminated so far as practicable.

Mr. R. W. BAILEY said he was sure that builders of steam-turbines would be indebted to the Author for his valuable Paper, first, because it emphasized the need of removing oxygen from boiler feed-water, and secondly, it might be inferred that, if it was not removed, serious corrosion of the plant might result. Corrosion in a steam-turbine was a much more serious matter than in a boiler; and there was no doubt whatever that oxygen was responsible in many cases for blading decay. Although materials specially resistant to corrosion were employed in the construction of steam-turbines, for example, 5 per cent nickel steel, high chromium steel, and special alloys, corrosion of blading might occur unless proper attention were paid to the feed-water. The firm with which he was engaged, namely, the Metropolitan-Vickers Electrical Co., had experienced cases of blading corrosion, and its research department had investigated the problem of water treatment with a view to its prevention.

The action of an iron deoxidizer of the type described by the Author was investigated, and the results obtained confirmed his remarks regarding its effectiveness. At first it was thought that iron turnings would meet ordinary requirements, but the idea was abandoned as it was feared that the water would traverse the mass in lanes, and uncertain and irregular action would result. He would like to ask the Author whether trouble of this kind was experienced with iron turnings. Attention was therefore directed to the use of expanded sheet steel, and Fig. 18, based upon experiments made with a small deoxidizer, showed the relation between the amount of iron, rate of flow, and oxygen removed as a percentage of that initially present. The action of such a deoxidizer was also investigated from a theoretical standpoint, in order that rational formulæ might be employed which could be used with some degree of confidence outside the range of the experiments. This was done in Fig. 18, which gave values for cases up to 500 sheets, although the experiments were only conducted over one-tenth of this range. It was found that the rate at which the iron absorbed oxygen was rather more than proportional to the concentration of oxygen (this might not be absolute, but might be really due to a more extended surface being offered where oxidization was most active), and increasing the velocity of flow increased the rate of absorption at the iron; but, as the quantity entering was proportional to the velocity, the percentage of oxygen removed from the water decreased with increasing rate of flow as would be expected. The curves showed

FIG. 18.



that the increase in efficiency with decreased velocity was appreciable. A rational formula taking into closer account the effect of concentration and velocity was not convenient for practical purposes, and the following approximate formula, which would satisfy most practical cases and was a basis of Fig. 18, might be given for the case where the water temperature was 15° C.

$$\text{Log}_{10} \frac{100}{100 - \text{P}} = \frac{3 \cdot 1 \text{ S N}}{100 + 12500 \text{ V}} + 0 \cdot 04$$

Where :—P = Percentage of oxygen removed.
V = Velocity of flow in feet per minute, based upon the gross cross-sectional area.
N = Number of sheets of expanded sheet steel.
S = Ratio :—$\frac{\text{Area of actual iron surface}}{\text{Plane area of sheet (one side)}}$.

The influence of temperature in increasing the rate of oxidation was most marked. Their information on this point was not very extensive, but it appeared to support the rough rule that it doubled for every 10° C. increase in temperature. He would like to ask the Author whether such a relation agreed with the curve exhibited by him.

He was most interested in the alternating flow arrangement developed by the Author in order to take advantage of a regenerative action. His firm had developed a similar arrangement for a different reason, namely, that the rate of corrosion was so much greater at the inlet end that, to secure something like uniform oxidation of the iron throughout the deoxidizer, it was necessary to employ the alternating flow principle. It should be mentioned that the rate of oxidation at different positions in a deoxidizer of the kind considered was given approximately in Fig. 18 by the ordinates of the different curves measured from the 100 per cent line.

The Metropolitan-Vickers Electrical Co. did not make deoxidizers, but they had looked into the question of their action and design in order that, where necessary, recommendations could be made to customers in connexion with the steam-turbines supplied. Fig. 19

showed diagrammatically a scheme recommended in the case of a large electric power-station in this country where corrosion had been traced principally to dissolved oxygen in the feed-water. Only the make-up water was passed through the deoxidizer, and this flowed under gravity from the storage tank A, *via* the pipe B and thermostat controlled heater E, to the deoxidizer C, its rate of flow being controlled by a float in the hot-well D. The valve arrangements for reversing the direction of flow and for permitting one side to be opened up while the other was in operation, thus enabling replacement of the expanded metal to be carried out without stopping the plant, as also the arrangement for shutting

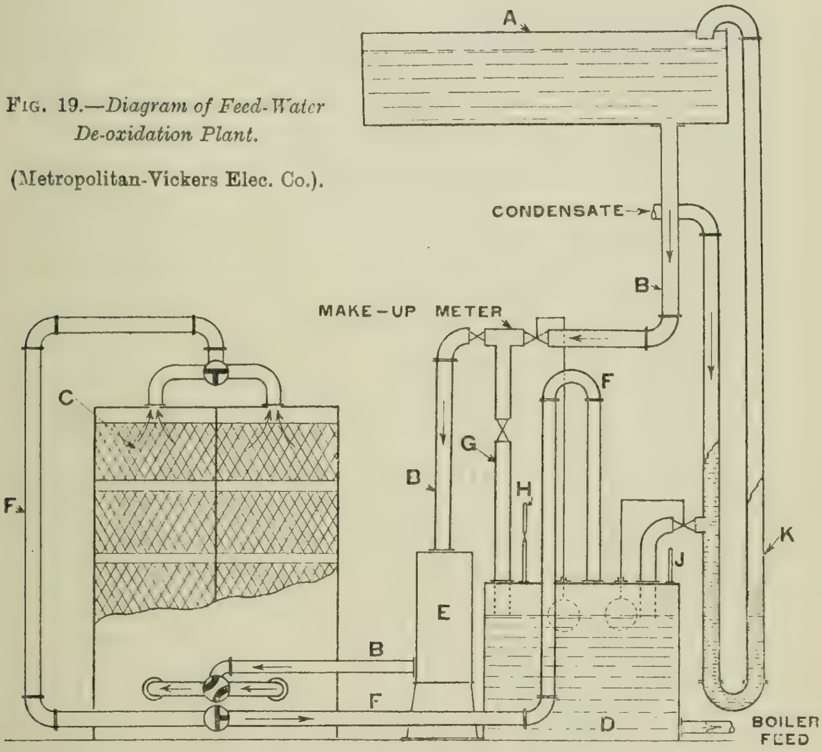


FIG. 19.—*Diagram of Feed-Water De-oxidation Plant.*

(Metropolitan-Vickers Elec. Co.).

down the deoxidizer completely, would be understood from the Figure. To prevent subsequent aeration of the make-up and of the condensate, the hot-well D was steam-sealed, exhaust steam from auxiliaries being led in at H and its supply adjusted so that a small escape took place at the vent-pipe J. To prevent aeration of the condensate and at the same time permit a simple delivery to the overhead storage-tank when the level in the hot-well closed off its flow thereto, an inverted siphon K was employed and the branch to the hot-well was "teed" off the inlet limb as shown A column of "dead" water existed below this connexion, and thus sealed the condensate passing to the hot-well from the atmosphere. The delivery pipe from the deoxidizer was carried up as shown at F, in order to keep the upper part of the deoxidizer under sufficient pressure to enable a snifting valve to release any gas that might accumulate when heating was employed. (*See* also page 342.)

Professor F. G. DONNAN, F.R.S., said he remembered that some years ago the question of the degassing of the water in the Calgoorlie water supply main, which had a very great length, arose, and he understood it was done by spraying at a reduced pressure. That was a very important question in connexion with conducting water over long distances and for general questions of municipal supply. It would be of interest if the Author could state how that method could be developed for general supply purposes. It was quite impossible to use a chemical method on a very large scale like that, and it would therefore be of interest to know if it was possible to use the physical method successfully. He thought that spraying by nozzles at a sufficiently low pressure-vacuum would not remove the oxygen sufficiently, but that was not a matter on which he possessed enough knowledge to give a valuable opinion.

With regard to the Author's scheme of a boiler acting as a water distiller, he remembered inspecting in South America a boiler system which worked in very nearly the same way. One boiler took the make-up feed, which was softened in the usual way, and acted as a water distiller to the other boilers. The condensed water came back, and there was a partial attempt at systematic blowing down, but it was not very great and was not particularly necessary. The boilers were mostly water-tube boilers working at 200 lb. pressure, and the water distiller was a Lancashire boiler working at about 50 lb. pressure.

Professor J. S. S. BRAME said he had been carrying out a good deal of work in connexion with boiler corrosion, and he was quite convinced that the question of oxygen in the feed-water was one of the utmost importance. The Author considered that the action of water and oxygen first produced ferric hydroxide, a similar action to that which took place in corrosion at normal temperatures. He (the speaker) was not sure, however, that the actions were similar in a boiler where the temperature was somewhere of the order of 200° C. In the deoxidizing of water by iron, the interesting point was the reduction of the Fe_2O_3 in contact with the iron in the absence of oxygen. At the point of entry the Fe_2O_3 existed as a maximum, but by passing the water in the other direction a dark greenish-black compound was obtained. It was an action which had been very largely overlooked, although it was mentioned in the old text-books; for instance, a very interesting account of that action would be found in Gmelin's Chemistry (vol. v, p. 185: 1851). The Author had postulated the formation of a hydrated magnetic oxide $Fe_3(OH)_8$. He (Professor Brame) would like to know whether there was any basis of analysis for such a formula. It was most difficult to get consistent results for the analysis of any of those products of oxidation except the fully hydrated oxide. From most forms of rust a considerable proportion of a magnetic oxide could be separated by grinding them up to a very fine state of division and flowing them by means of water past a powerful magnet. One was so accustomed to look upon it that the formation of ordinary Fe_3O_4, either as Fe_3O_4 or in the hydrated form, was only produced under special conditions that it was somewhat surprising to find that, if a plate of iron was left just awash in water, so that plenty of oxygen could get through, the red rust formed first of all, and that as the mass was built up there was formed underneath a darkish green or almost black compound which was strongly magnetic. Those were all reactions which related to the question of separating the oxygen from the water by the iron process, and in addition they must play a very important part in the whole question of corrosion. The solution of the problem lay very largely in finding out first of all what types of action were involved.

The Author had referred to magnesium chloride. It had had a lot of sins to bear and a lot of burdens to carry, but he was not sure that it was such a sinner as it had been made out to be. If the whole of the magnesium chloride remained in solution, he thought it was very doubtful whether that action of hydrolysis producing the hydrate and free acid actually did take place, but it had been shown by Hof that the development of free acid only became an appreciable reaction when the magnesium chloride was left as a deposit on the side of the vessel during evaporation.

Dr. W. R. ORMANDY said that a considerable number of years ago he had had a great deal to do with the installation of water-softening plants, and the experience which he had thus gained made him very cautious in expressing any opinion upon the reactions which took place. Particularly was this true regarding the mutual reactions taking place between oxygen and carbon dioxide in the presence of iron. Unlike Professor Brame, he thought that hydrolysis played an important part. A previous speaker stated that he did not find much evidence of electrolytic effects. It seemed to him that the extraordinary effects of local corrosion, spotting, in a boiler must to some extent be attributable to the heterogeneous nature of the metal which was employed. He thought most of the members who had had a good deal to do with boilers would remember occasions when an old boiler, made in the days when puddled iron was used, resisted all the waters used in it and gave no signs of corrosion, but when that boiler was displaced by a steel boiler then entirely different results were obtained, even with the same water which had been used successfully in the wrought-iron boiler. It seemed to him that that might be attributed to the fact that the steel almost invariably contained segregations rich in manganese. It was known, not only from the experiments which had been described in the Paper, but from other work that had been done on the subject, that manganese was an extraordinary material for acting as a carrier of oxygen. It was mixed with potassium chlorate in order to get oxygen off, and manganese sulphate was added in many reactions because it acted as an oxygen carrier. In many ways it was an ideal substance for the purpose.

It was difficult to grasp the details of the Author's continuous process, but it was clearly intended primarily for power-stations and marine work where surface condensers were employed. He would like to point out, however, that more boilers were probably employed in producing steam for industrial operations where the condensed water could not be returned to the boiler. This led one to inquire as to the possibilities of the application of the de-oxygenizing process in its application to such boilers. It was a very fortunate thing that the curve for the rate of the degassing reaction was such that at a temperature of 90° to 100° F., a very considerable velocity had already been acquired, because that was about the temperature at which every engineer desired the water to go into his economisers. It might, therefore, be assumed that water could be heated by waste steam to 90° F., sent through a de-oxidizing machine, and then passed through the economisers. Incidentally, eighteen months or two years ago, when getting quotations for economisers, he came to the conclusion that the makers were going to get over the difficulty by silver-plating them inside.

He would like to know whether the Author could say anything about the influence of traces of alkali on the rate of the removal of oxygen from boiler feed-water, because, as the members were aware, it was almost impossible to soften a water by any of the ordinary types of lime soda softening plants to within anything below 7 grains per 100,000 without having a certain amount of free alkalinity. He had met with a case of natural water which was so pure that it contained only 2 parts of solids per 100,000, but which seriously corroded steel boilers, and yet the addition of 2 grains per 100,000 of caustic soda inhibited that corrosion absolutely. He would like to know if the presence of free alkali in any way had that effect of stopping the absorption of oxygen in the degasser, or whether it necessitated the use of much larger degassers.

Mr. WILLIAM H. PATCHELL (Vice-President) said that some of the members had been striving for a long time to obtain closer association between the engineer and the chemist, and that had been brought about on the present occasion. The *entente cordiale* had been much in evidence during the last five years, and it had led to surprising changes, and he was glad that through the good services of M. Kestner it had led to the Society of Chemical Industry joining with the Institution in the present Meeting. Both Sir William Pope and Captain Sankey had said it was the inaugural meeting of the two bodies. He understood that it also set a precedent for the Society of Chemical Industry, in that he did not believe they had ever dared to meet anybody else before! He hoped the result of the combination would be thoroughly satisfactory.

M. PAUL KESTNER, in reply, said he was much obliged to the members for the kind reception that had been accorded to him. He was glad to hear the President, Sir William Pope, and Mr. Patchell agree with the suggestion he had made that the engineer and the chemist should work hand in hand, and that it would be of very great benefit to their industries. He would reply to the discussion in writing.

The Meeting then terminated.

Communications.

Mr. R. W. BAILEY wrote, in reply to Professor Brame's question relating to the character of the oxide coat, that he was struck by the remarkable uniformity and consistency in the action of their experimental deoxidizer, as shown by a period of operation of two to three months with only short stoppages at intervals for inspection or alteration in the number of sheets. During these runs no spottiness in the oxide coating occurred, which was very uniform in colour, red on the outside and greenish black below and next the metal. Probably the uniform conditions of flow, that could be obtained with expanded metal, accounted for the absence of a patchy coat. It would be interesting to know whether spottiness had been experienced with iron turnings, and he would like to ask for the Author's experience on this point.

With respect to the physical method of degassing described by the Author, namely, by exposing water to a reduced pressure, the action, of course, depended upon the magnitude of the partial pressure of the gas in the atmosphere to which the water under treatment was subjected, and this could be arranged to be very low indeed, although the total pressure might be appreciable. Thus water exposed to an atmosphere of steam if finely divided would be degassed, because the partial pressure of gas there might be nil or very small. In appreciating the advantages of the Author's continuous blow-down hot purification system of treatment, it was to be noticed that the inlet feed-water underwent degassing in this manner. To exploit this method to the full extent, however, it was necessary to draw off the gas liberated in order to have a low gas partial pressure. He would like to ask to what extent this was done. Instead of spraying water into an atmosphere of steam, a similar result, though not so complete, would occur if steam was bubbled through water. This happened in steam-boilers. A bubble of steam formed, having initially a gas partial pressure nil or very small, and as it rose it had a degassing action upon the water at its boundary. This was going on throughout the whole mass of the water, and thus it was that a large proportion of the dissolved gases was conveyed to the steam space and away to carry on corrosion of the plant beyond. This action of steam bubbles was not generally appreciated.

Messrs. J. H. COSTE and W. E. F. POWNEY wrote that the general question of gases dissolved in water was discussed at length by one of the writers in 1917 and 1918.* Since then they had had occasion to investigate the nature and amount of both gases and solids dissolved in the water and associated with the steam in a large power plant. They were generally in agreement with M. Kestner, but on some points they were unable to confirm his views. The greatly increased velocity of the softening process when it was carried out at an elevated temperature was undoubted. They could not, however, think that many boiler waters contained so much calcium sulphate that it would be partially precipitated during the softening process. The solubility reached a maximum at about 40° C., and at 100° was about 120 per 100,000 of water.

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* Jour. Soc. Chem. Ind. xxxvi, p. 846, xxxvii, p. 170.

The view that magnesium chloride was hydrolytically dissociated in dilute solutions with actual liberation of hydrochloric acid was, in their opinion, based on a misreading of Casaseca's Paper.* $MgCl_2 6aq$ seemed to be the stable form to 116·67° and between this and 181·5 $MgCl_2 4aq$, after his $MgCl_2 2aq$. See also Cribb (Analyst xxv, 1900, 169). As properly softened boiler waters were usually more alkaline than $P_H = 8$, the question of free acid could hardly come in. They were unable to agree with the view that the Author appeared to hold that sodium carbonate alone was better for softening than a mixture of this and lime. Lime had the great advantage of adding no soluble salts to the water, of removing magnesia from solution, owing to the low solubility of magnesium hydroxide and of directly reducing the admittedly very small hydrion concentration due to carbonic acid. The corrosion of boiler plates or of turbine blades was undoubtedly due, as the Author stated, to dissolved oxygen. Its action, however, appeared frequently to be that of a depolarizer, removing the ferrous ion from solution and forming finally that oxide which was in equilibrium with water at high temperatures, Fe_3O_4. It was the presence of dissolved oxygen alone which allowed the action of carbonic acid or of saline electrolytes to be continuous.

They had found that water condensed in the very diminished pressure obtained in the condenser of a large turbine fitted with separate and efficient water- and air-pumps was almost free from oxygen, whilst that from a condenser fitted with a single pump for gas and water might even be supersaturated. The almost air-free water took up a considerable proportion of oxygen—about 25 per cent of that required for saturation in flowing over a V notch and cascading down into the pipe leading to the feed-water heater. No doubt the turbulent flow was accountable for most of this, not the steady flow with unbroken surface over the V notch. In feed-water heater and open hot-well the concentration of dissolved oxygen would be about 70 per cent of saturation. Some reduction, principally shown indirectly by rusting in the water, but also by the reduced proportion of oxygen relative to "nitrogen,"* was found at the inlet of the economiser. The water at the outlet was difficult to sample satisfactorily, but the steam delivered to a turbine had been examined and found to contain much less oxygen than would correspond to the nitrogen in solution, showing a loss of oxygen in the economisers and boilers. Some carbon dioxide was also found.

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* Comp. Rend. 1853, xxxvii, p. 350.

The writers' experience with condensers fitted with efficient air-pumps convinced them that, at least as a counsel of perfection, the soundest way of securing water free from dissolved oxygen was to allow no opportunity for the water, which could be condensed practically gas-free, to absorb any. That is, to use as far as possible a closed circuit. If the make-up water was kept down to a minimum, suitable chemical or physical means, which might be such as the Author suggested, could be used for degassing it.

M. Kestner appeared to state that water at 100° C. and atmospheric pressure still retained a considerable proportion of oxygen in solution. This was correct in so far as the evolution of air required time, but there were several boiling-out processes for determining the gases dissolved in water which gave substantially exact results, although Leduc had shown that freezing was the most efficient means of degassing water. Of course, water at 100° C. under air, when the partial pressure of the air was 760 mm., would dissolve about 3 cm^3 per litre of oxygen. In any physical degassing process based on the use of an elevated temperature or reduced pressure or both, it was important to use appropriate means—spraying, dripping through small apertures, agitation, etc.—to obtain as large a surface of contact between the water and the atmosphere to which it was exposed.

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* i.e., nitrogen plus argon.

Mr. PERCY G. JACKSON wrote that he did not entirely agree with the Author's remarks in connexion with the continuous blowing-down of boilers. He had known cases in which this had been particularly useful, but he did not look upon it as generally necessary. The Author stated that, in order that periodic blowing-off from the lowest point in the boiler might be effective, a large quantity of water must be blown off at each operation. In the writer's opinion this was not at all necessary. If the periodical blowing-off was for the purpose of preventing the accumulation of mud, the opening of the blow-off cock for a few seconds at a time was all that was necessary.

He deprecated most strongly the idea of returning the blown-off water to the boiler. Though the Author removed the suspended impurities by passing the blow-off water through a settling chamber, he (the writer) did not see how any of the saline impurities could be removed, as the Author appeared to suggest. No boiler should be worked with a saline concentration exceeding about 5,000 grains per gallon, and as the solubility of all salts likely to be present in the water exceeded this, even at a temperature as low as 25° C., he could not understand how they could be removed by the simple process of cooling the blow-off water; and in the case of calcium sulphate, if present, this being more soluble at the lower temperatures than at the temperature of the boiler, it would have a tendency to redissolve rather than to be precipitated. As the prevention of undue accumulation of saline constituents was one of the two purposes for which blowing down was desirable, it appeared that the object was defeated by returning it to the boiler. The lower the saline concentration in the boiler the better, particularly if nitrates were present. The heat lost by allowing blown-off water to run to waste was so slight, provided the blowing-off was not excessive, that he could see no useful purpose in returning it to the boiler.

Mr. PHILIP L. RIVIERE wrote that he would like to support very strongly all that M. Kestner had said on the necessity for closer co-operation between the chemist and the engineer. At the London County Council Tramways Power Station at Greenwich, where for some considerable time now they had been fortunate in having the assistance of a fully qualified chemist working under the supervision of the London County Council Chief Chemist, the results following on the chemical work carried out had been most gratifying.

With regard to the question of blowing-down boilers, they had had at Greenwich the usual difficulties in deciding on the proper quantity of water to be blown out from time to time, and they were not assisted to any great extent by considering the procedure adopted elsewhere, as there appeared to be no standard test adopted for the determination of the degree of concentration of salts in boiler waters, and no agreed definite limit to the degree of concentration of solids allowable before blowing down was considered necessary. As a result of the work carried out by the chemist, it was decided that the chlorine content of the boiler water should be taken as a measure of the solids present in the water, and a figure of 400 parts of chlorine per 100,000 parts of boiler water was taken as representing the concentration allowable in ordinary circumstances. When boiler water was analysed and the chlorine content ascertained, the "alkalinity" was also taken, and for the conditions existing at Greenwich, it had been found that Chlorine + Alkalinity × 3 = the total solids present in parts per 100,000.

When taking samples of water from boilers for analysis, it had been found that great care should be taken to ascertain which position on the boiler was most likely to give samples that would be consistent and furnish reliable figures on which the general condition of the boiler water could be determined. Under the conditions prevailing at Greenwich, where Babcock and Wilcox boilers were set in pairs and were fed through feed check-valves on each drum supplied by means of a pipe controlled by a hand regulated feed-valve for each boiler, it was found that the concentration of solids in the outside drum was usually from 4 to 5 times as high as the concentration in the inside drum. The analysis of the feed-water at

Greenwich gave the following general results over a period of three months: Alkalinity 0·91, Chlorine 0·71, Hardness 0·73, while for the same period the corresponding figures for the make-up feed were: Alkalinity 6·8, Chlorine 2·5, Hardness 4·2, all figures representing parts per 100,000. It had been found that, in the case of the Babcock and Wilcox boilers, which were emptied and refilled with ordinary feed-water once every six or seven weeks when cleaning was carried out, the concentration of solids never exceeded 200 parts of chlorine per 100,000, and therefore no blowing down was necessary beyond opening and closing the blowdown cocks once per week to ensure that they were in working order.

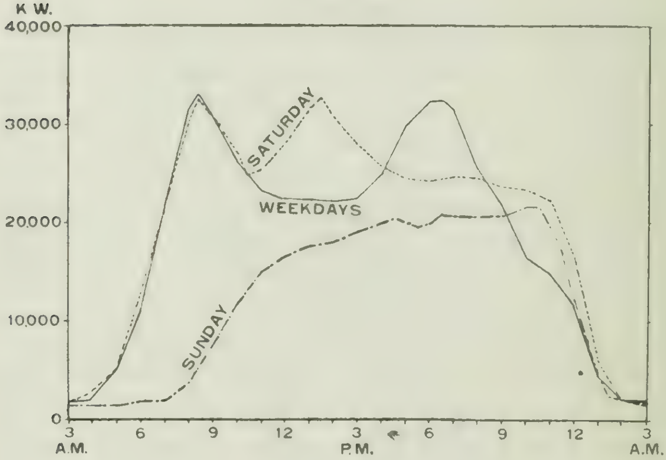
In the case of the Stirling boilers, the allowable concentration had been temporarily restricted to 50 parts of chlorine per 100,000, pending an alteration to these boilers, and it was found that this figure was reached in from three to five weeks, depending on the work done by the individual boilers. When the concentration reached the figure given, the boilers were blown down to the extent of about 250 gallons each night for four nights, when it was found that the chlorine content had been reduced from 50 to 30 parts per 100,000, after which the boiler would usually steam for about from 10 to 14 days before blowing down was again necessary. In consequence of the comparatively small amount of water blown down, the amount of make-up feed used was a small percentage of the total water evaporated. Under modern conditions, apart from slight condenser leakage, the make-up feed being the only way in which solids could be fed into the boilers, the importance of restricting the amount of make-up feed required was at once apparent. From the results obtained at Greenwich, where the make-up feed was from 3½ to 5 per cent, it would appear quite reasonable to expect that in a large modern power-station the percentage of make-up feed should not exceed from 3 to 4 per cent of the total water evaporated. The water blown out of the boilers did not as a rule exceed about 3·5 per cent of the make-up feed, but this did not include the complete changing of water when boilers were laid off for cleaning.

The water blown out of the boilers when under steam, together with the water emptied out when boilers were emptied for cleaning, represented about 7·5 per cent of the make-up feed. In order to keep a close check on the amount of make-up feed used and the amount of water blown out of the boilers, they had a meter on the make-up feed main and a " Lea " Recorder on the blow-down pipe-line, the introduction of the latter having proved particularly effective in preventing waste of water, through stokers having to lower the water level in banked boilers the feed-checks on which were leaking, and through the tendency to blow out water when the water level in working boilers had become dangerously high owing to lack of attention.

From their experience at Greenwich, it was difficult to conceive of a set of conditions which would justify the installation of M. Kestner's continuous blow-down system, as it would appear that the limit of concentration of solids in the boiler water would have to be considerably higher than was usually considered desirable, before the action of separating out he described could take place at the temperatures mentioned. The amount of water to be blown out in the ordinary way in a well-managed boiler plant would be so small that it would be very difficult to control the quantity within reasonable limits, as considerable trouble would be expected with regulating valves which would have to be operated under very severe conditions. He would like to know whether the Author had determined the degree to which he considered the various solids contained in boiler waters might be allowed to concentrate before it was necessary to blow down through his apparatus, and which method of determining the degree of concentration he had found most reliable under ordinary operating conditions.

With regard to M. Kestner's proposals, regarding the degassing of feed-water, it would appear that, in order to keep down the quantity of deoxidizing material used to a reasonable figure, it was necessary to arrange either for a closed circuit system or that deäeration should be carried out to a certain extent by physical means before the water passed into the Paris degasser. As a result of very careful observation and readings taken over a period of seven days, it was found that, at Greenwich with a load curve as shown in Fig. 20, they required a hot-well capacity of about 1,200 cubic feet to provide for the variation in the quantity of water carried in the hot-wells as reserve at different periods of the day. This hot-well capacity represented about 0·026 cubic foot per kw. of plant installed and appeared to be necessary, principally on account of the varying water-level in the boilers, of which the feed was hand-regulated. Although no doubt the capacity required in the hot-wells could be reduced considerably by the introduction of feed-water regulators, they would still require to have a large quantity of water in reserve to provide for variation in demand on the hot-wells, and it was at this point that the difficulties of degassing appeared.

Fig. 20.



When condensate left the condenser, it was, on account of the high vacuum now usually attained, almost quite free from oxygen, and in this state it was particularly liable to absorb a further quantity when exposed to the atmosphere, even for short periods. Some time ago tests were made at Greenwich to determine the amount of oxygen present in the condensate from one of the turbine sets, and the following figures were obtained from samples taken at the points given :—

—	Temperature of Water °F.	Dissolved Oxygen.		
		Cm^3 per Litre.	Lb. per Million Gallons.	Saturation.
				Per cent.
Condensate at—				
(1) Lea Recorder . Inlet	70	0·136	1.9	1·6
(2) Lea Recorder . Outlet	70	2·14	3·0	26·2
(3) Feed-Heater . Outlet	133	3·82	54·6	91·0
(4) Hot-well	110	4·22	60·3	93·3

In taking tests to determine the amount of oxygen present in condensate from various sets, it had been found that, in the case of Edwards' air-pumps, dealing both with air and water, the condensate was frequently found to be super-saturated with oxygen, while, in the case of sets where the air and condensates were dealt with by separate pumps, the amount of oxygen present in the condensate was almost negligible. The difficulty of storing water free from air, and at the same time allowing for considerable variation in level, was readily apparent, and the writer would be glad if M. Kestner could indicate in what way he proposed to provide for suitable hot-well capacity, such as was required in large power-stations.

M. PAUL KESTNER wrote that modern research in the metallurgy of iron and steel had been chiefly directed to improve their physical and mechanical resistance, and it was noticeable that this had been at the expense of their chemical resistance. Steel, which replaced wrought-iron everywhere to-day, had a much lower resistance to chemical reagents and the atmosphere than the latter, and there were wrought-iron fire-bars forged in the eighteenth century which were still in a perfect state of preservation. There could be seen, in sugar factories in the Colonies, rails and rolling stock made at the beginning of the sugar industry which were still doing good service, whilst similar material of recent origin had rusted after a very few years' use.

Referring to Professor Hinchley's remarks (page 332), the material used in degassers was not manganese cast-iron but manganese steel, cast-iron not being readily oxidizable when exposed to the air. The presence of graphitic carbon in general indicated a feebly oxidizable substance, even in the presence of manganese. Manganese steel in which the carbon was in the combined state was most favourable for oxidation. In addition, it would be impossible to obtain very long and thin turnings if manganese cast-iron were used. There were no traces of sulphur in the turnings used.

Replying to Mr. Arthur Spyer (page 332), good results could not be obtained if ordinary turnings were employed, as they tended to pack and channels were formed. Special turnings were therefore used made in the form of ribbon from 4 feet to 5 feet long. These gave a very homogeneous mass and had proved quite successful in practice. By the old process it was found that the turnings were used up and collected in heaps; the fillings also broke and crumbled on becoming rusty. Washing broke them still further, and the rust made them less able to absorb the oxygen. In the process of regeneration this was avoided; the mass kept its reducing properties sensibly constant until completely used up.

The distilled water produced in evaporators had the same oxygen content as the water before distillation, owing to the oxygen remaining in the vapour. This must therefore be degassed within the same limits as other boiler feed-water. If it were desired to avoid concentration in the boilers, the blow-down must be taken into account, particularly where boilers were using purified water only, without return of condensed water, as the boiler feed-water, after its passage through the purifier, contained soluble salts. These consisted of soda, sulphate of soda, and chloride of sodium. In general, carbonate of soda was present in the greatest quantity; sulphate of soda only existed to any amount in water of great permanent hardness, and the chloride of sodium only existed in water which contained it originally, or which contained chloride of magnesium. In all purified waters there was carbonate of lime in solution, concentrated to saturation point at the temperature at which purification took place. All these salts concentrated in the boiler except the carbonate of soda, which concentration was limited by the continuous blow-down, and the carbonate of calcium, whose solubility was low and could not exceed its saturation at the boiler temperature. The latter salt gave rise to the formation of muds which were removed by the continuous blow-down and deposited in the purifier; thus there remained sulphate of soda and chloride of sodium. These salts concentrated until they were deposited in the purifier, due to the difference of solubility at the different temperatures obtaining in the boiler and purifier, these deposits being in proportion to the difference of saturation percentages at the two temperatures. This concentration represented for each of these two salts more than 300 grammes per litre. Such an increase would produce mud in the boilers and an elevation of the boiling point; thus it must be avoided.

Mud was produced in the boilers from the moment that a certain limit of viscosity was passed; and the latter was a function of the concentration and the temperature. The elevation of boiling point followed the Raoult's law. If one exterpolated for the saturation concentrations, and applied the formula

$$T = \frac{520 \times C}{M}$$

C being the concentration, and M the molecular weight of salt dissolved, then it was found for a concentration of 1 per cent an increase of 0·088 and for 30 per cent 2·64. The elevation of boiling point corresponded to a very slight diminution of vapour tension and did not sensibly affect evaporation in the boilers. In practice it was found impossible to obtain perfectly dry steam, and, if the concentration in the boiler were raised, the water entrained by the steam would contain a larger quantity of dissolved salts and thus a larger quantity in the condensed water. The presence of these salts in the steam was apt to deposit sediment in the tubes of the superheaters and to attack the turbine blading. The concentration in the boilers must therefore be limited, the maximum depending on the initial concentration of dissolved salts in the purified water, and this limit was again dependent upon the type of boiler.

It has just been shown that there are numerous physical reasons for avoiding concentration in boilers; but on the other hand, reasons of a chemical nature opposed too low concentrations. The work of Friend and Brown and Heyn and Bauer, had proved that there existed for each salt critical low concentrations for which the attack of the iron was a maximum, and that this attack diminished sensibly for higher concentrations. For carbonate of soda a concentration was rapidly reached, not only where the attack of the iron was stopped, but even where the soda protected the metal against the action of other salts; whilst the action of chloride and sulphate of soda decreased proportionately with the concentration, but at saturation point it was still appreciable. It was necessary, according to the above-mentioned Authors, that the soda should reach a concentration in the boiler of more than 1 per cent, and it could be affirmed that for concentration of 1 per cent, the corrosive action of the other salts was sensibly lessened. This latter case corresponded with that obtained with continuous blow-down. To sum up, in the case of purification by continuous blow-down, the limitation of concentration in the boilers ought to be governed by physical reasons and be determined quantitatively for each case.

There were two methods, chemical and physical, for limiting the salt content in boilers :—

The *Chemical* method applied particularly to waters rich in sulphate of calcium. It consisted of introducing in the purifier carbonate of baryta which, by double decomposition with the sulphate of calcium, gave carbonate of calcium and sulphate of baryta. The two latter salts were extremely insoluble, and allowed complete elimination of the sulphate of calcium. No method was at present known for the elimination of chloride of sodium.

The *Physical* method was the simple one of blowing down the boilers periodically. The concentration in the boilers obviously would not increase if the quantity of salt which entered in a day was equal to that which was blown down in the same time.

Let N be the number of cubic metres of raw water introduced in the boiler in twenty-four hours.

c the concentration of the raw water in grammes of salts per cubic metre.

V the volume of the boiler in cubic metres.

C the concentration limit of the salts in the boiler in grammes per cubic metre.

$\frac{1}{p}$ the fraction of the volume of the boiler emptied by the purge in twenty-four hours.

The quantity of salts entering the boiler for twenty-four hours is

$$Nc.$$

The quantity of salts eliminated in twenty-four hours is

$$VC \times \frac{1}{p}.$$

Let these quantities be equated then

$$Nc = CV \frac{1}{p}.$$

The concentration C found in the boiler at equilibriums will be

$$C = \frac{Ncp}{V}.$$

Note that $\frac{N}{V}$ is the number of boilers filled per day with the raw water.

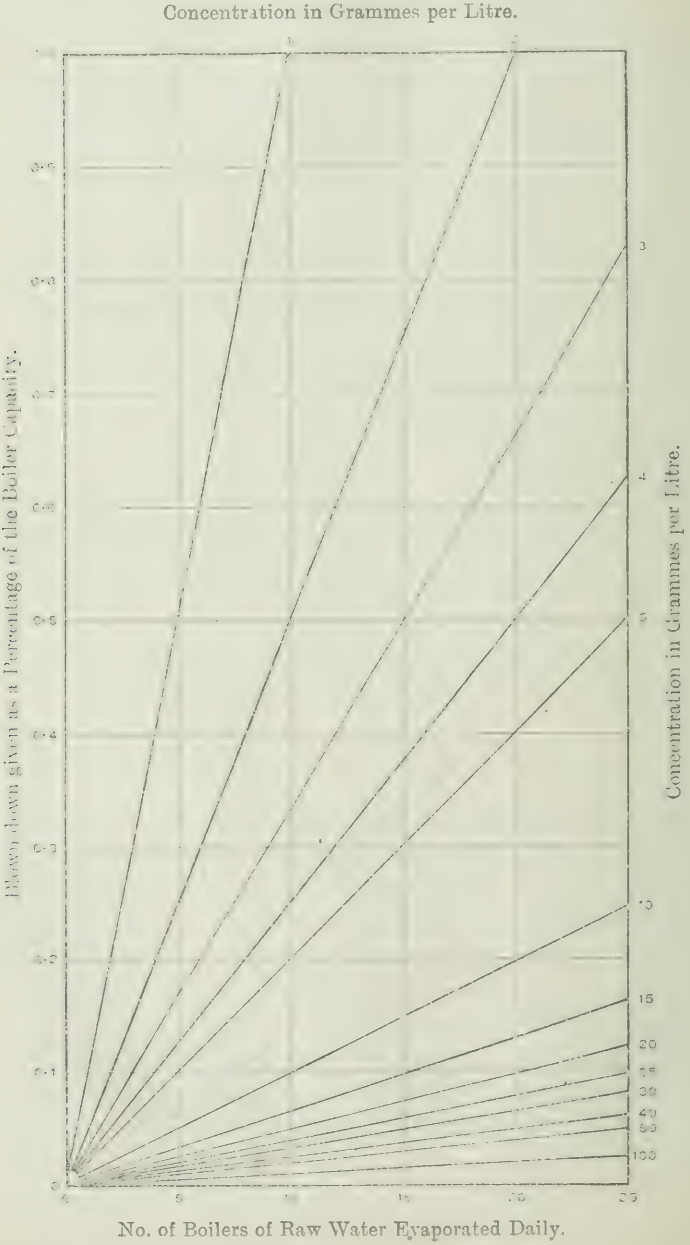
Let $$A = \frac{N}{V},$$

then $$C = c \times A \times p.$$

The final concentration of the boiler would then be equal to the product of the concentration of the raw water by the number of boilers of raw water evaporated per twenty-four hours and by the number of blow-downs necessary to empty the contents of one boiler. In other words, it was proportionate to the concentration of the raw water by the output of the boiler, and inversely to the quantity of the blow-down.

The preceding calculation enabled the following curve to be drawn, Fig. 21. It was thus seen that the concentrations might be limited without important losses of hot water. and blowing down

FIG. 21.—*Concentration Limit of Water from Boilers for the Water Circulation containing* 0·1 *Gramme per Litre, of Dissolved Salt.*



was not so important a factor where the salt content in the water was low. The installations most unfavourable were those which evaporated purified water and which did not recover the condensed steam. In those cases where the condensed steam was reintroduced into the boiler, it was only necessary to blow down a small quantity. Boilers using distilled water similarly only blew down a very small percentage, since the distilled water contained a very small quantity of salts. It had been found that continuous blow-down was the least costly method of purification. As much on account of the price of the plant as of their running cost. Added to these advantages was the fact that no incrustations were formed in the boiler and that consequently cleaning was unnecessary. Galvanic action did not appear to play any large part in the corrosion of boilers.

In reply to Mr. R. W. Bailey (page 334) the Author stated that the employment of the special ribbon gave excellent results, and did not allow of short circuits or channelling (*see* reply to Mr. Spyer). The average relationship established between the speed of degassing at low and high temperatures was shown on Fig. 13 (page 320). So many factors intervened that it was impossible to obtain a general formula, and relationships could only be established for particular cases. Tests had been made on expanded metal, but the net cost was about three times that of iron turnings for the same output, and for the same weight the turnings had a surface about four times greater.

With reference to Professor Donnan's remarks (page 338), chemical degassing was inapplicable to drinking water; the corrosion in town's water pipes must be overcome, either by the action of an incrusting coating by a lining of cement in the iron piping, or by using armoured cement feeders.

In reply to Professor Brame, the Author stated that what took place in a boiler at 200° C. could not be observed; but when it was opened, rust was found as a result of the attack of the iron. It was probable that others had ascertained the transformation of the oxides of iron. Without referring to Gmelin or to Hermes, references would be found in the most recent works and more on a level with actual experience (*see* Bibliography, page 360—article of Von Siegmon). All possible products between FeO and Fe_2O_3 and their hydrates were produced in this blackish-green oxide. The product that had been examined had a percentage of oxygen which did not correspond either to one of the oxides or one of the hydrates. In other cases, different results had been obtained. It seemed that the temperature played a great part in the degree of oxidation of the final product. At the present moment researches had not been finished on the subject of this state of oxidation of the iron.

With regard to the subject of chloride of magnesium (page 340), it had not been found that a small amount of soda in the water modified the action. It was thought this was due to the very great oxidizable properties of the iron turnings.

In reply to Mr. Bailey's communication, irregularity or "spottiness" had never been observed in the layer of oxide in degassers where iron turnings were used : it always had a very uniform colour. Degassing by atomizing the water in a space containing steam could only give good results by aspirating with a pump the gases and steam which were in contact with the water. This was done in the Elliott process by the use of a high vacuum and vaporization of the water which had, under this small pressure, an almost explosive transformation into steam. The extraction of the steam necessitated a powerful pump ; the condensed steam contained air which had to be eliminated. If it were sent again through the plant, a continual enrichment in air was produced in the water to be degassed. There was no doubt that good results had been obtained by this process, but it was open to the following objections:—

(1) It was difficult to obtain sufficient vacuum when the amount of water to be degassed was large.

(2) In this plant, where the water and the steam were under a very reduced pressure, particularly so in the water extraction pump, a very small leak sufficed to destroy the effect of the degassing.

In regard to the communication by Messrs. Coste and Powney, the facts quoted on the subject of sulphate of calcium were known ; that was why in the text, it was stated that the diminution of solubility of the $CaSO_4$ produced by the elevation of temperature was of very little importance in that case. The reference quoted on the subject of $MgCl_2$ was not known, but there had been no cases observed of corrosion by chloride of magnesium where the water was alkaline; but there were numerous examples in the case of collieries where the water was neutral, or slightly acid. On the other hand, it was not contended that purification by soda alone was better than by lime and soda; the point being that, in the particular case of continuous blow-down, purification by soda was more advantageous.

As to the condensed water regaining oxygen, it was very difficult to avoid in an ordinary or even specially made circuit; pumps and hot-wells of variable level were also causes of air re-entering. The question was solved in the following way :—

(1) Maintain a small pressure in the total water circuit, thus leaks could only take place from the interior to the exterior. All pumps should be under load as much as possible, thus there could be no re-entering of air.

(2) The degasser was under load and placed immediately in front of the feed-pump.

(3) For hot-wells of variable level, in the circuit type there was always feed-water at high temperature, thus a cushion of steam could be maintained over this water to create pressure in the space of hot-well not filled by water and to avoid re-entering of air. The special hot-wells were combined with a degassing device placed therein, which removed the oxygen from the water before it left the hot-well; thus there could be large variations in the demand for water.

As for elimination of gases from the water by boiling, it must be remarked that this only took place completely by prolonged boiling, and that it would be impossible industrially to degass by such boiling which would necessitate removal of an important quantity of water at the same time as the gas. An equilibrium was established between the partial pressure of the oxygen in the steam of the oxygen content of the water; in order that this should be nil, the steam must be pure. It must be noted that the oxygen content of the water was infinitely small in comparison with the volume of steam that this water represented.

Continuous blow-down was the cheapest process, and if it were a question of particularly difficult cases, as Mr. Jackson indicated, it was generally advisable to apply it throughout. Continuous blow-down had the one aim of avoiding calcareous precipitation in the boilers. It was not a question of attaining concentrations, or sulphate of soda, for example, would be precipitated, but only of limiting the concentration of carbonate of soda and producing precipitation in the purifier by difference in temperature of part of the $CaCo_3$ of the blow-down.

With regard to Mr. Riviere's remarks, the question of purification ought not to be considered only from the point of view of central stations where 98 per cent of condensed water was recovered, but from that of the more numerous works using purified water only, which did not recover their condensed water or use it for other purposes than feeding the boilers.

Bibliography.

Die Bekampfung von Rost and Abzehrungen an Dampfkesseln, by E. Hohn. Zurich 1919.

Die Ursachen der Zerstorungen an Wasserrohrkesseln im Turbinenbetrieb und die zu ergreifenden Gegenmassnahmen, by Von Seigmon, *Zeits. der Ver. deut. Ing.* Nos. 21, 22, 23 May 1919.

Dampfkessel schäden and Ihre Möglichste Veihutung, by Frantz. Kattowitz, 1915.

Die Reinigung des Kesselspeisewassers, by Claussen. Leipzig, 1921.

Epuration perfectionné des eaux pour Chaudiers. Paris, *Chemic et Industrie*, Dec. 1920.

Les filtres à tournure de fer et leur emploi pour la suppression des corrosions. Paris, *Chaleur et Industrie*, July 1920.

Enquête sur les grandes centrales thermiques, by H. Dieterlen, *Chaleur et Industrie*, Nos. 1 and 2, 1920.

The Corrosion of Iron and Steel, by Newton Friend, Longmans Green, 1911.

Zeitgemasse Kesselanlagen fur Elekhesche Kraftwerke, by Ott. Hanover, 1920–21.

The Institution of Mechanical Engineers.

PROCEEDINGS.

MARCH 1921.

An ORDINARY GENERAL MEETING was held at The Institution, London, on Friday, 18th March 1921, at Six o'clock p.m.; Captain H. RIALL SANKEY, C.B., C.B.E., R.E., ret., *President*, in the Chair.

The Minutes of the Meetings on 18th February and 4th March were read and confirmed.

The PRESIDENT announced that the following 66 Candidates had been duly elected:—

MEMBERS.

BEXON, William Collier,	Kilmarnock.
CREWE, Vere,	Klipdam, C.P.
IGNATIEFF, André,	London.
ORMESHER, Edward,	Manchester.

ASSOCIATE MEMBERS.

BENT, John Charles,	London.
BIRCH, Thomas,	Nottingham.
BRADBURY, Arthur Walter,	London.
BROWN, Charles,	London.
CHEW, William Edward,	Manchester.
COBB, Charles Ernest,	London.
COOPER, Basil Pomeroy,	Leicester.
DANIELS, George William,	Port Sunlight.
DAVIS, William Kidd,	Dublin.
FELL, Louis Frederick Rudston, D.S.O., O.B.E., Lieut.-Col., R.A.F.,	London.
GRANSDEN, Charles Lewis, Captain, R.A.O.C., I.O.M.,	Devonport.
GUEILIKMAN, Michael,	London.
HUDSON, Richard John Harrington,	London.

Jarred, Harry Arthur,	Newcastle-on-Tyne.
Keal, Henry Houghton,	Baghdad.
McQuade, William, M.B.E.,	Edinburgh.
Meadows, Frederic Charles,	Johannesburg.
Morgan, William,	Stoke-on-Trent.
Morton, William Ash,	London.
Pleydell-Nott, John George Latham, D.S.O., Major, R.A.S.C.,	London.
Potts, Sydney Charles, Major, R.E.,	London.
Richardson, Thomas Brook,	Birmingham.
Ronald, James, M.B.E.,	Woolwich.
Sethna, Rustam M.,	Ernakulam.
Suckan, Charles Albert,	Manchester.
Thorp, Herbert,	Lancing.
Twinch, Walter,	Calcutta.
Wilson, Thomas Martin,	Stockton-on-Tees.

GRADUATES.

Baker, Henry Wellstood,	London.
Blood, Robert Bindon,	London.
Bryant, Roger Havelock,	London.
Chandler, Leonard Robert,	London.
Cheshire, Leslie Jack,	Manchester.
Clynes, William,	London.
Colebrook, Christopher Merrill,	London.
Coles, Walter Valantine,	London.
Cramer, William,	Worcester.
Douglass, Leslie,	London.
Dunn, Ernest Vercoe,	London.
Eatough, Clifford,	Manchester.
Edwards, Cyril Arnold,	London.
Finch, Herbert John,	London.
Fraser, Donald Stuart Denholme,	London.
Glaister, Edwin,	London.
Heywood, William Johnson,	Manchester.
Holbein, Arthur Montague,	London.
Hughes, Humphrey Morgan,	London.
Husk, Arthur Cecil,	London.
Jones, Eric Langford,	Liverpool.
Kerridge, Walter,	London.
Knowles, Thomas William George,	London.
Lyall, Alexander, Jun.,	Birmingham.
Moyes, Thomas Frederick,	London.
Peters, Harold,	London.
Price, Joseph Vincent,	Hull.
Randerson, George,	Huddersfield.
Robertson, Donald Athole,	London.
Ross, Hubert Hope,	London.
Shephard, George Arthur,	London.
Shirtliff, Edward Matthew,	London.
Simmonds, Stanley Herbert,	London.
Smith, Hubert Alfred, B.Sc.,	Gravesend.

The President announced that the following five Transferences had been made :—

Associate Members to Members.

Hobson, John William,	Newcastle-on-Tyne.
McFadyen, Alexander,	Dunedin.
Redfern, Charles Julian,	Derby.
Smith, Alexander John,	Tokyo.
Smith, Horace Reginald,	Birmingham.

The following Paper was read and discussed :—

"Contact Pressures and Stresses"; by Professor E. G. Coker, D.Sc., F.R.S., *Member*, of London, K. C. Chakko, M.Sc., and M. S. Ahmed, M.Sc.

The Meeting terminated at a Quarter to Eight o'clock. The attendance was 94 Members and 23 Visitors.

The Paper on "Contact Pressures and Stresses" was also discussed at :—

Manchester, in the Engineers' Club, on Thursday, 21st April; Mr. Charles Day, *Chairman of the Local Branch*, in the Chair.

CONTACT PRESSURES AND STRESSES.

By Professor E. G. COKER, M.A., D.Sc., F.R.S., *Member*,
K. C. CHAKKO, M.Sc., and M. S. AHMED, M.Sc.,
of University College, London.

The application of a load over a very limited portion of the surface of a solid body generally causes intense stresses in the immediate neighbourhood of the place of application, while the manner in which the load is distributed over the area of contact, when two bodies are pressed together, may vary considerably with the physical characteristics of the materials brought into contact, also the form of each body and the mode of application of the load. The mode in which a load is distributed at a contact surface is all important as regards the stresses at neighbouring points, since St. Venant's principle of equi-pollent load systems does not then apply, nor can the distribution be determined except by experimental means. At a considerable distance away from the contact area the way in which the distribution occurs is relatively unimportant, since the stress distribution is hardly affected thereby. In practical applications great concentration of loading is avoided, as far as possible to prevent permanent injury to the material, but there are many cases in which intense loading pressures are inevitable, as, for example, knife-edge and roller bearings and the line contact of gear-wheels. The contact pressure of the driving-wheels of a locomotive on the rails affords another instance of intense local bearing and stress, the constant application of which has a deteriorating effect on both wheels and rails.

In the testing of materials there are also cases of great stress concentration, such as indentation tests for hardness, in which a spherical ball or a cone is pressed against the material by a load sufficiently intense to deform the material permanently. A variety of other examples will readily occur to engineers in which the study of contact pressures and the stresses produced by them is of practical importance, and offers a considerable field for theoretical and experimental investigation. A simple typical case is that of a single load applied normally to the edge of a plate, and such a case has been examined experimentally by Carus-Wilson* using a beam of glass resting with its narrow edge on a flat plate with a sheet of thin paper interposed between the surfaces.

These experiments showed some interesting features, requiring further explanation, which is given later in this Paper, and they may be illustrated by an experiment made on a beam 6·1 centimetres long, 2·0 centimetres deep, and having a thickness of 0·65 centimetre. A steel roller of 0·2 centimetre diameter was pressed against the centre of this beam by aid of a screw and the temporary double refraction caused by loading was observed by aid of two Nicol's prisms crossed at 45° to the axis of the beam, with a quarter wave plate of mica placed in front of the analysing prism, so that the plane containing the optic axis was at right-angles to the length of the beam. With this arrangement the effect produced at any point in the normal line of load is that of no stress, wherever the difference of phase between the ordinary and extraordinary rays traversing the beam is equal and opposite to the difference of phase produced by the mica plate, and there will therefore be a black spot as the Nicols are crossed. The position A of this spot on the normal is determined and the value of p-q determined from the colour band at this point.

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* "The Influence of Surface Loading on the Flexure of Beams," by Prof. C. A. Carus-Wilson. Phil. Mag., December 1891.

A second quarter-wave plate is now superposed on the first, and the black spot then moves up the normal to a point B, where the value of p-q is doubled.

The second mica plate is now removed and the load diminished until the black spot with one mica plate is brought to the point B. In this way a number of points on the normal are found, at any one of which the stress difference is twice that of the point below. As the stress at any point of the beam varies directly as the load on the roller, it is now possible to trace the variation of stress difference along the normal through the point of application of the load. One set of observations is plotted in the accompanying Fig. 1 to a horizontal scale of phase differences, and it is found that on the upper half of the beam these points are found to lie very nearly upon a hyperbolic curve, but on the lower half there is a marked difference and the stress begins to increase again as the distance from the loading point becomes greater. As the roller indents the beam to a small extent, this asymptote to the hyperbola is actually not in quite the same position as is assumed in the simple theory, while the points of observation near the lower bearing surface lie somewhat off the hyperbolic curve.

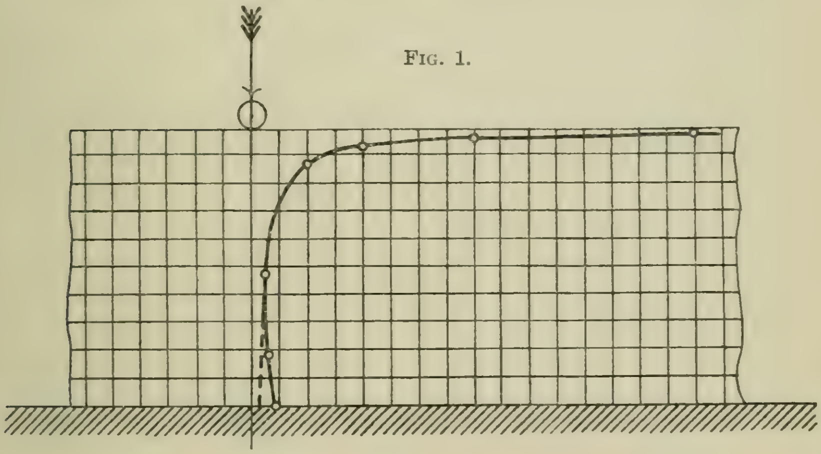


FIG. 1.

In a further experiment to establish the hyperbolic law with greater certainty, the observations were limited to the upper half of the beam. The load was applied by a screw as before, until seven interference fringes appeared under the roller when viewed in light from a sodium flame. The distance along the normal from the point of contact to successive fringes was measured by a micrometer eye-piece divided to thousandths of an inch.

These distances require correction for the indentation caused by the loading pin, in order that they may be regarded as measured from the asymptote. To find this correction, it was assumed that it has a constant value δy, and by taking any pair of reliable observations the required correction can be found.

This correction is therefore to be added to the experimental numbers. The interference fringes are caused by the stress-differences N corresponding to the first seven ordinal numbers, and hence if the values of the corrected distance C and N are multiplied together, they should give a constant value, if the hyperbolic law holds. This is substantially found to be the case.

The experiments also showed that, for this kind of loading, all the points where the stress difference is constant lie on circles touching the upper surface of the beam at the point of contact.

These investigations, so far as they extend, are approximately consistent with the theory of a single concentrated load at a point in a semi-infinite plate, and before describing further experimental investigations in which stress distribution has been measured over a considerable area around the points of application, it will be convenient to give the results of analysis for this case.

The stress function $\chi = c \cdot r\theta \sin\theta$ is a solution of the general equation $\nabla^4_{r_1\,\theta}\chi = o$ (1) for plane stress, and from it we obtain :

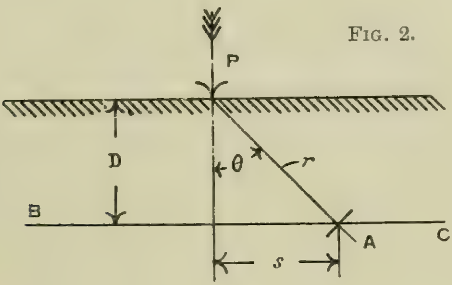
$$\widehat{rr} = \frac{1}{r} \cdot \frac{\partial \chi}{\partial r} + \frac{1}{r^2} \cdot \frac{\partial^2 \chi}{\partial \theta^2} = 2c\frac{\cos\theta}{r}$$

$$\widehat{\theta\theta} = \frac{\partial^2 \chi}{\partial r^2} = o$$

$$\widehat{r\theta} = -\frac{\partial}{\partial r}\left(\frac{1}{r} \cdot \frac{\partial \chi}{\partial \theta}\right) = o \quad . \quad . \quad . \quad . \quad (2)$$

The expression for $\widehat{rr}$ shows that this stress becomes very large as r approaches zero, and its form indicates that, at the origin, the state of stress is produced by normal concentrated stress at a point, or since we are considering plates, by loading along a line in the surface and normal to this bounding surface. The value of the constant c may be obtained from the consideration that the sum total of all the normal components of stress across a plane BC, Fig. 2, at any depth D parallel to the surface must equal the load at the origin. The radial stress rr at $A = 2c \frac{\cos\theta}{r}$, and its

FIG. 2.



component normal to the plane BC is therefore $\widehat{rr} \cdot \cos^2\theta = 2c \frac{\cos^3\theta}{r}$. If, therefore, all these values are summed on the infinitely extended plane, the resultant value is—

$$P = 4c \int_0^{\frac{\pi}{2}} \frac{\cos^3\theta}{r} \cdot ds \quad . \quad . \quad . \quad . \quad (3)$$

where $s = D\tan\theta$, and therefore $ds = D\sec^2\theta \cdot d\theta$. Also $r = D\sec\theta$.

Putting these values into equation (3), we obtain—

$$P = 4c \int_0^{\frac{\pi}{2}} \frac{\cos^3\theta}{D \cdot \sec\theta} \cdot D \cdot \sec^2\theta \cdot d\theta$$

$$\text{or} \quad P = 4c \int_0^{\frac{\pi}{2}} \cos^2\theta \cdot d\theta = \pi c \, , \quad . \quad . \quad (4)$$

Hence a normal force P corresponds to a simple radial distribution

$$\widehat{rr} = \frac{2\,P}{\pi} \cdot \frac{\cos\theta}{r} \quad . \quad . \quad . \quad . \quad (5)$$

there being no other stress as appears from Equations 2 (page 368).

Along the normal at the point of application of the load

$$\widehat{rr} = \frac{2\,P}{\pi} \cdot \frac{1}{r} \quad . \quad . \quad . \quad . \quad (5a)$$

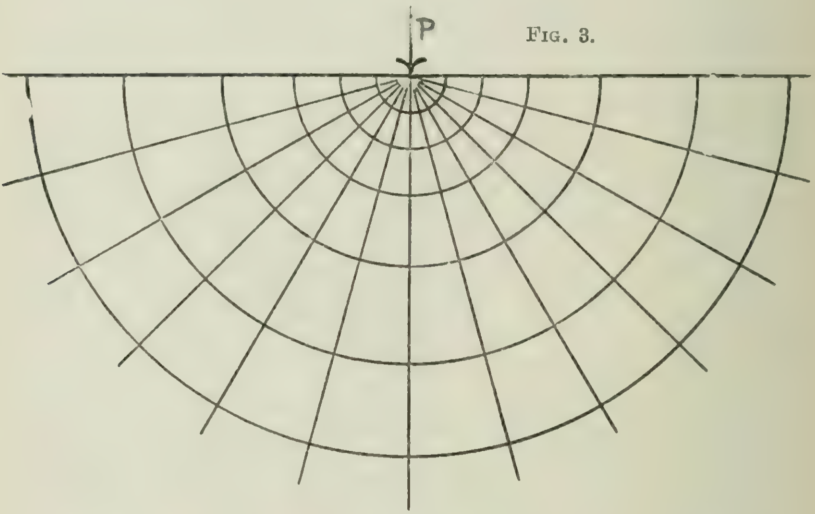


FIG. 3.

so that the stress falls away according to a hyperbolic law as Carus-Wilson's experiments show.

In order to obtain the form of the curves for which the stress difference is constant, we have, since $\widehat{rr}$ is the only stress, at any point R_o below the point of application of the load

$$\widehat{rr} = \frac{2\,P}{\pi} \cdot \frac{1}{R_o} = \text{a constant} = c_o.$$

Hence for any other point

$$\frac{2\,P}{\pi} \cdot \frac{\cos\theta}{r} = \frac{2\,P}{\pi} \cdot \frac{1}{R_o},$$

or

$$r = R_o \cos\theta \quad . \quad . \quad . \quad (6)$$

corresponding to circles touching the plane boundary at the point of application of the load.

The distribution of stress due to a line source P, normal to a semi-infinite plane, is therefore purely radial and the lines of principal stress consist of circles around a point of application intersected by straight lines passing through the origin as Fig. 3 shows. The magnitude of the radial stress reaches a maximum value for any radius on the vertical line through the origin as the Fig. 4 indicates, while the colour bands marking the positions of equal stress difference should be circles touching the contour at the point of application.

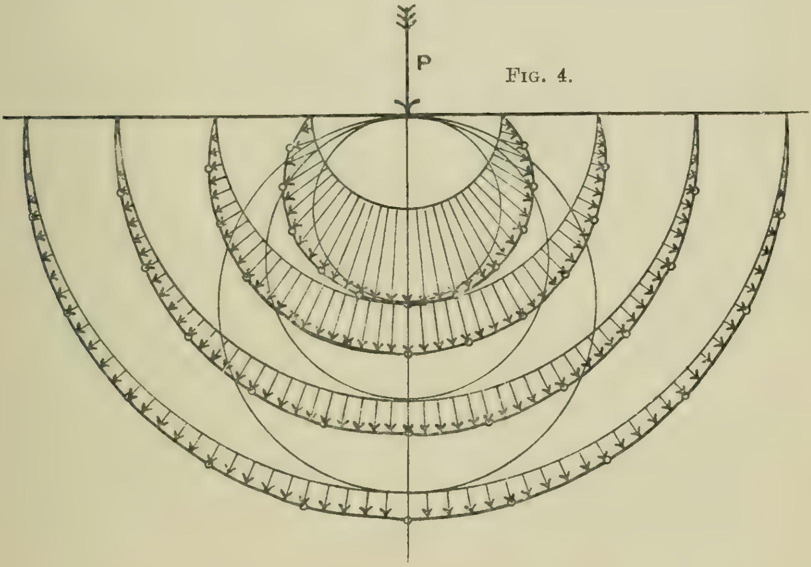


FIG. 4.

Experiment, however, shows that such a simple stress condition is very difficult, if not impossible, to realize in practice, since line contact across the thickness of a plate cannot be maintained if any effect is to be measured or rendered visible optically. Moreover, the necessity of supporting the lower edge of the plate at a finite distance away introduces a system of applied forces which do not correspond with the conditions assumed in the simple theory above, and the disturbing influence of these latter is generally important. It seems probable that the discrepancy noticed by Carus-Wilson in the hyperbolic law of stress distribution along the vertical Fig. 1 (page 367) may be due to this latter cause, and that his curve of distribution is substantially correct for the experimental case taken.

Apparently the applied balancing forces along the lower side tend to concentrate around the central part of the bearing area, owing to the tendency of the edges of a block, of rectangular cross-section, to lift when one of its surfaces is pressed against another flat surface, of much greater area and approximately equal hardness, by a load applied at the centre of the face. This can be readily observed when a block of india-rubber, say 6 inches long, of square section, and 1 inch side, is pressed against a hard surface by a central load ; a visible uplift of the ends is then found, and contact is not obtained there. It seems probable, therefore, that even so hard a material as glass, when pressed against a flat metal plate with thin paper between, will behave in a similar manner, although the strains are now so minute that the uplift is not discernible.

In order to confirm this view, an experiment was made in a form of testing-machine* designed to give pure compression.

Calibration of this machine shows that the load applied by the lever arm is transmitted without perceptible loss to the specimen between the pressure plates. In order to test the correctness of the view expressed above as to the distribution of the load, a plate was prepared of as large a size as could be used in this testing machine. It was of rectangular form, 5·14 inches long and 2½ inches deep, with one long side accurately bedded against a flat steel plate supported on the lower plate. Pressure was applied over an area extending 0·1 inch over the top edge and symmetrically disposed with reference to the central vertical line.

This form of distribution was chosen in order to prevent injury to the plate and to avoid permanent deformation at the area of contact.

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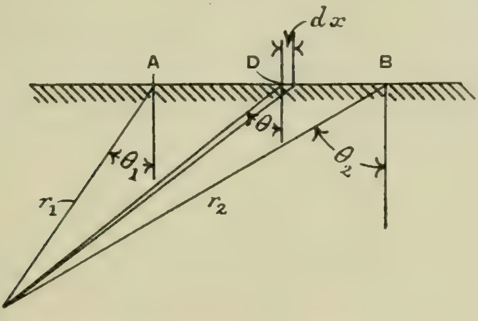
* "A column testing-machine," by E. G. Coker, Proc. Phys. Soc. of London, vol. xxv, Part II, 1913.

On the assumption of a uniformly distributed load over a limited portion of a semi-infinite plate, an expression for the stress distribution can be obtained by considering stress functions of the form $cr^2\theta$. If to a point A on the straight line boundary A B, Fig. 5, there corresponds a stress function $\chi_1 = cr_1^2 \cdot \theta_1$, the resulting

FIG. 5.



stress distribution at any point r_1, θ_1, with reference to the origin A is—

$$\widehat{r_1 r_1} = 2c \cdot \theta_1,\ \widehat{\theta_1 \theta_1} = 2c\,\theta_1 \text{ and } \widehat{r_1 \theta_1} = -\,c.$$

If to any other point B on this boundary there is also a corresponding stress function $\chi_2 = -\,cr_2^2 \cdot \theta_2$ the stress at any point r_2, θ_2 is—

$$\widehat{r_2 r_2} = 2c\,\theta_2,\ \widehat{\theta_2 \theta_2} = -\,2c\,\theta_2 \text{ and } \widehat{r_2 \theta_2} = +\,c.$$

For both systems on the line A B

$$\Sigma\,\widehat{rr} = o, \Sigma\,\widehat{r\theta} = o \text{ and } \Sigma\,\widehat{\theta\theta} = -\,2c\,\pi = \text{a constant of value say } p.$$

Also, as can be easily verified, there is no stress over the rest of the boundary, while at infinity all stress vanishes.

Hence the stress function

$$\chi = -\,\frac{p}{2\pi}\,(r_1^2 \cdot \theta_1 - r_2^2 \cdot \theta_2) \quad . \quad . \quad . \quad (7)$$

corresponds to the case of a normal pressure uniformly applied to a limited portion of the plane boundary of a semi-infinite plate.

The stress at any point C having co-ordinates $r_1, \theta_1, r_2, \theta_2$, with reference to the origins A, B, is obtainable by integrating the effect of all the elemental loads on the boundary A B. At any point D the load intensity p on an element dx of the boundary gives a radial stress at C of

$$\widehat{rr} = \frac{2p \cdot dx}{\pi} \cdot \frac{\cos\theta}{r} = \frac{2p \cdot r\,d\theta}{\pi \cdot \cos\theta} \cdot \frac{\cos\theta}{r} = \frac{2p}{\pi} \cdot d\theta$$

where $r_1\theta$ are the co-ordinates of C with reference to D as origin.

As will appear immediately, it is convenient to reckon the stress produced at C with reference to an origin D (r, ϕ) having a vector C D bisecting the angle A C B.

The normal, tangential, and shear stresses at C, due to the distributed load $p \cdot dx$, are then

$$\begin{aligned} \widehat{rr} &= \frac{2p}{\pi} \cdot \cos^2\phi \cdot d\phi \\ \widehat{\theta\theta} &= \frac{2p}{\pi} \cdot \sin^2\phi \cdot d\phi \\ \widehat{r\theta} &= \frac{2p}{\pi} \cdot \sin\phi \cdot \cos\phi \cdot d\phi \quad . \quad . \quad . \quad (8) \end{aligned}$$

Also $\theta - \phi = \frac{\theta_1 + \theta_2}{2}$ a constant and hence $d\theta = d\phi$.

Summing the stresses for uniformly applied load over the strip A B, we obtain at the point C

$$\widehat{RR} = \frac{2p}{\pi}\int_{\theta_1}^{\theta_2} \cos^2\phi \cdot d\phi = \frac{p}{\pi}\left\{(\theta_2 - \theta_1) + \sin(\theta_2 - \theta_1)\right\}$$

$$\widehat{\Theta\Theta} = \frac{2p}{\pi}\int_{\theta_1}^{\theta_2} \sin^2\phi \cdot d\phi = \frac{p}{\pi}\left\{(\theta_2 - \theta_1) - \sin(\theta_2 - \theta_1)\right\}$$

$$\widehat{R\Theta} = \frac{p}{\pi}\int_{\theta_1}^{\theta_2} \sin^2\phi \cdot d\phi = o$$

Or writing $\theta_2 - \theta_1 = a$ we obtain—

$$\left.\begin{aligned} \widehat{RR} &= \frac{p}{\pi}(a + \sin a) \\ \widehat{\Theta\Theta} &= \frac{p}{\pi}(a - \sin a) \\ \widehat{R\Theta} &= 0 \end{aligned}\right\} \quad . \quad (9)$$

as the stress system at the point C.

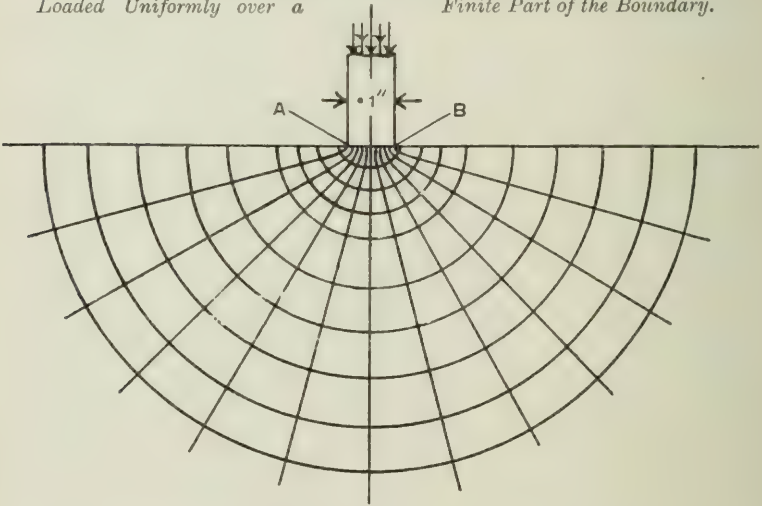
TABLE 1.

1 inch Width $\frac{p}{\pi} = 100.$

$d = \frac{1}{2} \cot \frac{\alpha}{2}$	$\widehat{rr}$	$\widehat{\theta\theta}$	$\widehat{rr} + \widehat{\theta\theta}$	$\widehat{rr} - \theta\theta$
∞	0	0	0	0
11·4520	—	0·01	17·45	17·24
5·7150	34·81	0·09	34·90	34·72
2·8356	69·11	0·71	69·82	68·40
1·8660	102·4	2·36	104·72	100·00
1·3738	134·1	5·53	139·62	128·56
1·0723	163·9	10·66	174·52	153·20
0·8661	191·3	18·12	209·44	173·20
0·7141	216·2	28·22	244·36	187·94
0·5959	238·1	41·14	279·24	196·96
0·5000	257·1	57·08	314·16	200·00
0·4195	273·0	76·04	349·04	196·96
0·3501	286·0	98·01	383·96	187·94
0·2887	296·0	122·84	418·88	173·20
0·2332	303·5	150·30	453·80	153·20
0·1820	308·6	180·08	488·72	128·56
0·1340	311·8	211·80	523·60	100·00
0·0882	313·4	245·04	558·48	68·40
0·0438	314·1	279·34	593·40	34·72
0	314·16	314·16	628·32	0

These expressions have been obtained by J. H. Michell* in a somewhat different manner. The forms of the expressions show that the lines of the principal stress are ellipses, Fig. 6, intersected by orthogonal hyperbola, both systems having the same foci, A, B. At the area of contact, therefore, these lines are markedly different from the case of line contact, but at a moderate distance away the curves are hardly distinguishable from circles and orthogonal straight lines having an origin at the centre of the pressed area.

FIG. 6.—*Lines of Principal Stress in a Semi-infinite Plate Loaded Uniformly over a Finite Part of the Boundary.*



The most convenient method of examination is to compare the actual values of stress difference (p–q) along the central line with those obtained by calculation. These latter may be readily obtained from Equations 9, and are shown in Table 1 (page 375), where $\frac{p}{\pi} = 100$, with a bearing area of one unit in length for a plate of unit thickness. The values of $\widehat{rr}$ and $\widehat{\theta\theta}$ and their sum and difference are readily applicable to any case, and are plotted in Fig. 7

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* "The Inversion of Plane Stress." Proc. London Mathematical Society, vol. xxxiv.

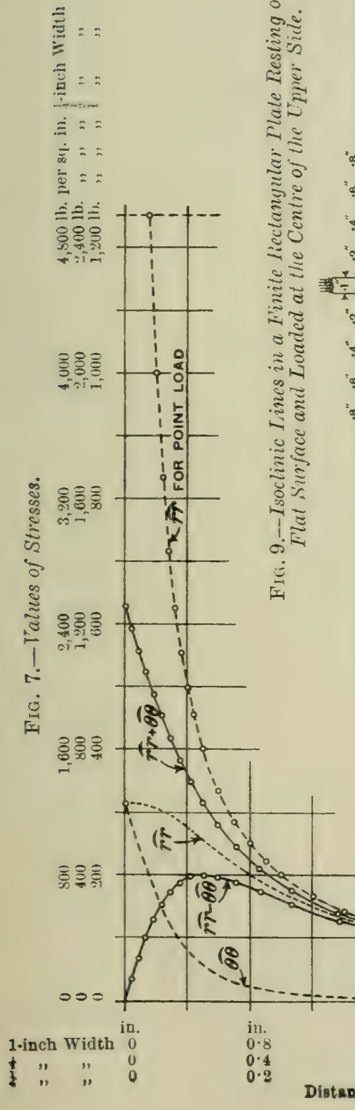


FIG. 7.—*Values of Stresses.*

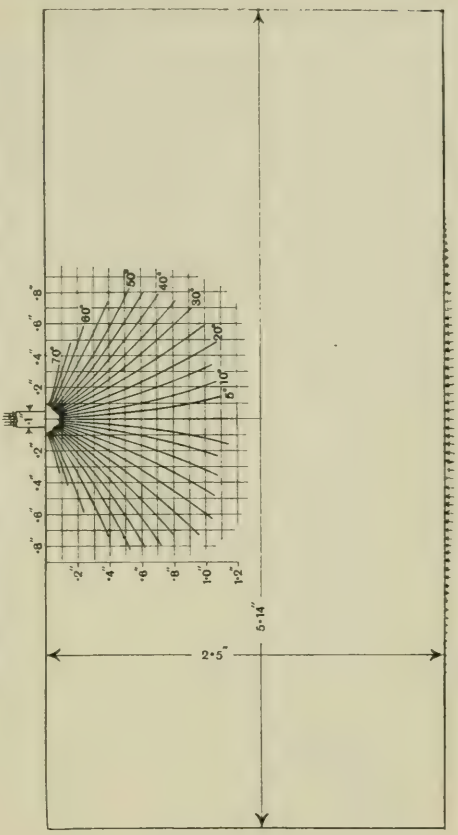


FIG. 9.—*Isoclinic Lines in a Finite Rectangular Plate Resting on a Flat Surface and Loaded at the Centre of the Upper Side.*

to three different scales to facilitate subsequent comparisons. It is of interest to note that $(\widehat{rr}-\widehat{\theta\theta})=p-q$ along the central line, has a zero value at the origin, and a maximum value when $\alpha=\frac{\pi}{2}$ corresponding to a distance of half the width of the contact area.

An examination of the colour bands, Fig. 8, Plate 16, for the plate described above shows, however, that the assumptions on which calculation is based are difficult to realize. The extreme edges of the contact area show brilliant colour banding, in addition to circles passing through points A and B, Fig. 6 (page 376), which calculation, based on uniform surface loading, lead one to expect. Circular bands of this type corresponding to the equation—

$$p-q=\sqrt{(\widehat{rr}-\widehat{\theta\theta})^2+4\,\widehat{r\theta}^2}=\widehat{\mathrm{RR}}-\widehat{\Theta\Theta}=2\frac{p}{\pi}\sin\alpha$$

are very well marked, although usually not perfectly symmetrical and often slightly elliptical, but in addition there are lobed-shaped curves starting from the end points A and B, which penetrate into the plate and indicate a variation from uniform distribution.

The colour scheme, therefore, points to the conclusion that the pressure distribution is not uniform, but, as its nature is not completely determined from these optical measurements, the further elucidation of this matter is deferred until the method of separation of p and q has been described. There is, however, nothing to indicate from a superficial examination of the colour bands that the stress distribution at a considerable distance away differs from that obtained from the assumption of uniformly applied load, but measurements of the inclinations of lines of principal stress, by aid of plane polarized light, show however that the lines of equal inclination Fig. 9 (page 377) are curves bending outwards and indicating stress concentration at the centre of the support, and this is confirmed by the lines of principal stress, which are easily obtained from the former set. These lines bend over to meet the bottom edge, as Fig. 10 (page 380) shows, and probably meet the contour at an angle slightly different from 90°, owing to the tangential stress produced by friction between the two surfaces.

It seems probable, therefore, that this system of stress distribution will show greater values along the central line than are given by the expression $\widehat{RR} - \widehat{\Theta\Theta} = 2\frac{p}{\pi}\sin\alpha$, and this is found to be the case, as Table 2 and Fig. 10 show. In all cases the observed values are higher than those obtained by calculation, and particularly so when the distance below the contacting surfaces is such that the law of equi-pollent loads might possibly be considered to be applicable. In this case, however, no part of the plate in the neighbourhood of the central line is really sufficiently removed from either stressed boundary to justify the application of this principle, and the contact pressures undoubtedly differ in a marked manner from the simplifying assumptions of uniform pressure distribution of ordinary theory.

TABLE 2.

Stress Difference along Central Vertical Line.

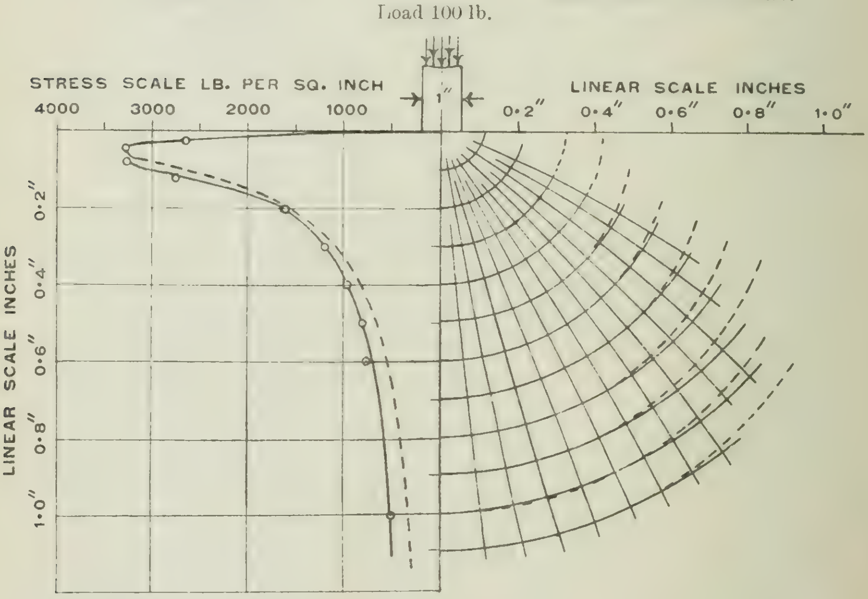
Distance.	$p - q$ lb. per square inch.	
	Calculated.	Observed.
Inch. 0	0	0
—	2,300	2,660
—	3,260	3,270
—	3,000	3,300
—	2,370	2,775
0·2	1,570	1,635
0·3	1.080	1,215
0·4	820	985
0·5	660	815
0·6	555	785

At the upper surface the great stress at the extreme boundaries of the loaded area may possibly be due to intense local shear, and although the displacement of points near the centre appears to be greater than at the ends, the strain at the latter probably reaches a maximum. This view appears to be confirmed by the phenomena sometimes observed at the bases of metal columns set on stone or concrete foundation blocks, where it is sometimes noticeable that the print of a very rigid base plate is bordered with flakes detached from the friable lower block.

FIG. 10.

Distribution of Principal Stress-Difference along the Central Vertical Line.

Lines of Principal Stress in a Finite Rectangular Plate Loaded at the Centre.



At the lower surface the concentration is undoubtedly towards the centre, and on referring to the work * of Professor L. N. G. Filon, F.R.S., a confirmation was obtained on theoretical grounds. It is there shown that the pressure Q on the lower side of a block of depth b and of infinite length is expressed by an integral of the form—

$$-Q = \frac{2W}{\pi b}\int^{\infty} \frac{\sinh u + u \cosh u}{\sinh 2u + 2u} \cos \frac{ux}{b}\, du$$

---

* "On the approximate solution for the bending of a beam of rectangular cross-section under any system of load," by L. N. G. Filon, Trans. R. S. Series A., vol. 201.

where u is the variable, W is the concentrated load, and x the distance from the central line. This integral can be evaluated as a convergent series, and the distribution is found to have a high central value, which falls rapidly and becomes zero for a value of $x = 1 \cdot 35\, b$, and from that point the beam is no longer in contact with the lower surface. There can be no doubt, however, that if uniform pressure could be applied over a small finite area of a semi-infinite plate the measured stress distribution would agree with the calculated values.

As will be shown in a later section, the application of a uniform pressure over a limited area has only been approximately realized in one special case.

So far no attempt has been made to separate the principal stresses p and q from the experimental determinations of their difference and inclination, but this may be accomplished from this data by methods which have been described * but are often difficult to carry out with accuracy in the complicated cases which occur in engineering practice. It is, in general, simpler to measure an independent function of p and q, such as $(p + q)$—as suggested by Mesnager.† If a thin plate of any shape is stressed by forces in its own plane, the strains at any point r, θ in terms of the principal stresses $\widehat{RR}$ and $\widehat{\Theta\Theta}$ are given by—

$$m\,\mathrm{E}\,e_{rr} = m \cdot \widehat{\mathrm{RR}} - \widehat{\Theta\Theta}$$

$$m\,\mathrm{E}\,e_{ee} = m\,\widehat{\Theta\Theta} - \widehat{\mathrm{RR}}$$

$$m\,\mathrm{E}\,e_{zz} = -\,(\widehat{\mathrm{RR}} + \widehat{\Theta\Theta})$$

where e_{zz} is the strain measured in the direction of the thickness, and therefore a measurement over the thickness of the plates of

$$-\frac{m\,\mathrm{E}}{d}\int_{-c}^{+c} e_{zz} \cdot dz$$

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* "Experimental Determination of the Distribution of Stress and Strain in Solids." By Professors Filon and Coker. B. A. Report, 1914.

† "Mesure des efforts intèrieurs dans les solides et applications," by A Mesnager, Buda-Pesth Congress of The International Association for Testing Materials, 1901.

gives a mean value of the stresses $\widehat{\mathrm{RR}}+\widehat{\Theta\Theta}=p+q$. These correspond to the generalized stresses of Filon.* In practice, it is inconvenient to divide each measurement by the values of the constants m and E, and the sum of the stresses is more easily obtained by comparing the change of thickness observed with that obtained from a similar plate under uniform tension or compression stress. If P_t is a uniform tension load applied to a member of rectangular section $\mathrm{A}=bd$ and P_c is a similar compression load. We have —

$$\epsilon^{1}_{zz} = -\frac{\mathrm{P}_t}{bd}\cdot\frac{1}{m\,\mathrm{E}\,d} = -\frac{p_t}{m\,\mathrm{E}\,d}$$

$$\epsilon^{11}_{zz} = -\frac{\mathrm{P}_t}{bd}\cdot\frac{1}{m\,\mathrm{E}\,d} = -\frac{p_c}{m\,\mathrm{E}\,d}$$

$$\text{also}\quad \epsilon_{zz} = -\frac{p+q}{m\,\mathrm{E}\,d} = -\frac{\widehat{\mathrm{RR}}+\widehat{\Theta\Theta}}{m\,\mathrm{E}\,d}$$

$$\textbf{Hence}\quad \frac{\epsilon_{zz}}{\epsilon^{1}_{zz}} = +\frac{p+q}{p_t}$$

$$\text{or}\ p+q = +\,p_t\,\frac{(\epsilon_{zz})}{(\epsilon^{1}_{zz})}\ \text{or} = p_c\,\frac{\epsilon_{zz}}{\epsilon^{11}_{zz}}$$

a relation which is independent of the constants.

The strains are very small, and, as the plate is usually thin, measurements of very small changes are required. With the transparent nitro-cellulose used in this investigation, a fair value of E is 300,000 in pound and inch units, and a corresponding value of m is $2\cdot5$.

The lateral alteration in a plate of $0\cdot15$ inch thickness for a stress of 1 lb. per square inch is 2×10^{-7} inches, and to determine stress distribution to an accuracy of 5 lb. per square inch a lateral extensometer is required reading to 10^{-6} inches. This offers no serious difficulty so far as the instrument itself is concerned, provided temperature conditions can be maintained very uniform, as the coefficient of expansion of the material is of the same order as the measurements.

An improved form of lateral extensometer was devised for these measurements, reading to one-millionth of an inch. This was used throughout the investigations described below.

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*Ibid., page 381.

In general a large number of lateral measurements, and a corresponding number of optical observations, are required to obtain an accurate estimate of the stress distribution. A usual number for each is 20 per linear inch or 400 to cover a square specimen of one inch side. On this account an adjunct measuring instrument is required to bring the needles into their correct position. A convenient way of effecting this is to support the instrument by a three-wire suspension from a frame capable of adjustment horizontally and vertically by measured amounts.

For this purpose the frame may be carried on slides moving on horizontal bars and adjusted in position by a fixed horizontal micrometer bearing against a suitable projection of this frame. A second and vertical micrometer is arranged to lift the frame bodily through any required distance. The range of movement, in each direction, may be extended beyond the range of the micrometers, to any required amount, by using distance blocks of known dimensions. For both optical and mechanical measurements the most convenient method of working is to make observations with a small load, and then with a much greater one the difference between the measurements being taken to eliminate errors which may arise in working from zero loads and from the effects of any slight initial stress which may be present. This involves a double series of measurements, but the increased accuracy justifies the extra labour involved. A disturbing influence which requires elimination is due to the slightly varying thickness of a specimen cut from a plate. These differences are usually of the same order as the measurements, unless the faces are specially prepared.

A fair example of the condition of a piece cut from a sheet as received from the maker is shown by the measurements obtained on the lower half of a square of 1 inch side and approximately 0·251 inch in thickness. The variation with reference to a point for which $x = 0{\cdot}4$ and $y = 0{\cdot}2$ from the bottom left-hand corner is shown in the accompanying Table 3, and it is worthy of note that the principal differences occur in general along the edges, and

TABLE 3.

Variation of Thickness in a $\frac{1}{4}$-inch Plate.

One Unit = 10^{-5} inches.

—	0·01	0·05	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	0·95	0·99
0·5	−50	−18	− 6	− 6	− 8	− 5	+ 1	+ 8	+13	+16	+16	+ 8	−22
0·4	−42	− 9	+ 3	+ 3	− 1	+ 1	+ 3	+ 9	+13	+16	+20	+14	−15
0·3	−29	−11	+10	+ 7	0	− 3	− 4	− 3	− 2	+ 3	+ 8	+ 4	−21
0.2	—	+28	+26	+19	+ 9	0	− 6	−10	−12	− 9	−12	− 2	−16
0·1	+ 3	—	+39	+26	+12	+ 9	− 1	− 8	−11	− 9	0	0	−24
0·05	+23	+39	+57	+51	+38	+25	+14	+ 7	+ 1	+ 1	+11	+10	−13
0·01	−35	−11	+ 1	−11	−11	−21	−33	−39	−40	−48	−46	−51	−76

especially at the corners where the cut surfaces intersect. The exposure of a freshly-cut surface without subsequent polishing is, in fact, followed by a slight change at the edges due possibly to the escape of a small part of a volatile constituent. In a thick plate the effect is often noticeable from the appearance of a white line along the contour when the specimen is viewed in a polariscope. In thin specimens this effect is shown but rarely, even after the lapse of years.

In general, therefore, the stresses at the edges are somewhat more difficult to determine, but at a free contour the measurements are not complicated by the necessity of separating the principal stresses, since both $(p+q)$ and $(p-q)$ are equal, and the directions follow the contour.

The mechanical labour of recording all the measurements required proved far too great to allow of much progress, and in order to dispense with book-keeping, a cylindrical recorder was constructed having a barrel pivoted on a vertical axle and capable of vertical adjustment by aid of a lever operated by a screw, so that the zero can be adjusted as the extensometer is moved about. The positions of the reflected image are marked on a sheet of squared paper secured to the cylinder, and the differences obtained between the initial and final loads are measured between the corresponding curves drawn through the points of observation.

Discussion of the Possible Errors and Corrections of the Mechanical Measurements.

Temperature Variations.—All the measurements were made in a room in the basement of the engineering wing of University College, where the temperature conditions vary somewhat, and this especially affects observations of change of thickness. This is especially noticeable during the winter months, when it is found that readings taken in a warm room on a Saturday differed materially from similar readings taken on the following Monday morning before the temperature conditions become normal. These differences disappear with the establishment of the working temperature of about 60° F. In some cases it has been found necessary to place a paper shield round the extensometer in order to avoid changes of temperature due to air currents.

Errors of Position.—The extensometer is supported independently of the specimen, and is registered thereto by reference to some convenient point or line when the initial load is applied. The readings are then taken for this load and also for a final load, which latter produces strains slightly altering the configuration of the specimen. In these experiments the diminution in the length of the central line and the changes in width of the specimen are both easily measurable, and by working with reference to this central line and the edge of the bottom pressure plate as axis, a correction can be applied to the position micrometer which renders this error practically negligible.

Corrections may also be required owing to the calibrating member for optical observations not being quite of the same thickness as the specimen under test, and also for the change in thickness caused by stress when both are compared, and the stress intensity measured by producing a dark field at the point required. This is most conveniently carried out with a tension member. If then the initial thickness of the specimen is x, and the calibrating member y, then at any point of the specimen the final thickness will be

$$x\left\{1 \pm \frac{p+q}{m\mathrm{E}}\right\}$$

where the + sign is to be taken for all the cases examined here; while for the tension member the corresponding thickness is

$$y\left\{1 - \frac{f}{m\mathrm{E}}\right\}$$

where f is the corresponding stress.

When a black field is established, since the optical constants are the same for both specimens, we have

$$(p-q)\,x\left(1 + \frac{p+q}{m\mathrm{E}}\right) = fy\left\{1 - \frac{f}{m\mathrm{E}}\right\}$$

$$\text{or} \quad p - q = f\,\frac{y}{x}\left(1 - \frac{p+q+f}{m\mathrm{E}}\right) \quad \text{very nearly.}$$

In general $y = x$, although sometimes a slight difference occurs, while $(p+q)$ and f are rarely more than 1,500 lb. per square inch, and m and E have values of about 2·5 and 300,000 respectively. Hence $(p+q+f)\ /m\mathrm{E} = 1/250$ or 0·4 per cent, so that occasionally corrections are required when high stress differences are found, but as a rule the error is small and vanishes entirely when $(p+q)$ and f are of opposite signs. The difficulty of providing a member in pure compression is, however, too great to make this a desirable feature of the measurements, as the results which follow show clearly.

Errors may also be caused by friction of the pivots, and of the measuring needles in their bearings, while minute scratches or irregularities at the surface show themselves by sudden jumps in the readings. If, however, the testing-machine used is gently tapped with a pencil, or, if massive, vibrated by the action of a small electric bell attachment, the instrument takes up the position due to the strain. The effect of a minute scratch sometimes renders it necessary to take readings on each side of the position, and to use these to obtain a value at the required point.

The usual tangential errors of the readings on the barrel are allowed for, and in some cases these are considerable. As an example an extreme case may be quoted, in which the reading h is 12 inches above the level of the reflecting mirror and the distance l is 32 inches. The movement of the mirror is approximately tan 0·175 or $\theta = 10^\circ\ 37'$, and the error in assuming that $ld\theta = dh$ is $l\ (d \tan \theta) - ld\theta = l \tan {}^2\theta\ d\theta$, or very approximately $\tan {}^2\theta dh$. The error in reading is thus about 3 per cent. All readings are therefore corrected by reference to curves constructed for any required relation between h and l. In making this correction, the height of the reflecting mirror must be found relative to the readings on the drum, but any small error in the measurements of this height affects the correction by not more than one-tenth of the error made, and is therefore negligible. Moving the extensometer to different positions on the specimen also alters this height, but this can be corrected by the screw controlling the vertical position of the drum. A horizontal shift from the vertical plane passing through the spindle and the central position of the extensometer tends to increase the readings, since the image of the wire is received on a more distant part of the cylindrical drum. A movement of half an inch in either direction causes an error of one part in 2,000 for the drum used, which was $8\frac{3}{4}$ inches in diameter, and thus is insignificant unless the specimen is very wide. In this latter case the drum is arranged to move on a cross slide parallel with the extensometer. There are a number of possible minor errors, such as might occur owing to the recording cylinder not being vertical, or truly cylindrical, or due to imperfect ruling of the squared paper, but all these have been eliminated.

Early experiments showed some perplexing variations in the reading of the lateral extensometer under identical conditions, and these were found to be due to (1) errors in the dividing of the micrometer head, (2) errors in the screw, and (3) variations in the friction of the points and bearings of the measuring needles when moved over bounding surfaces of the specimen. The first was very much reduced by a newly graduated head, the second by using a very long screw and nut, and the last by increasing the rigidity of the supporting frame and careful rounding and polishing of the contacting areas.

Experiments were then made under good temperature conditions by two observers, who recorded their results quite independently, and a summary of these observations is given in the accompanying Table 4 (page 390), in which different positions of the screw and micrometer head are examined. It will be observed that the highest set of readings is obtained for the second position of the screw and the divisions 320°–360° of the head ; and that the last three positions deal only with this range.

Taken as a whole, the deviations are small, and although the maximum difference from the mean is 2 per cent, the average difference from the mean is only 0·02 per cent for the whole series. The distance of the scale is taken much greater in some cases, to make the readings more sensitive, although this is usually accompanied by some loss of definiteness of the projected image of the cross wire.

Discussion of the Possible Errors in the Optical Measurements.

An investigation * was also carried out to examine the mechanical properties of nitro-cellulose compounds used in this and other investigations and also the law of its optical behaviour, and it is material to the present experiments to remark that under tension stress the law of optical retardation is shown to be proportional to stress and not to strain, and that it is linear even when the material is stressed far beyond the elastic limit and very near the yield-point. Hence the optical measurements require no correction at high stresses, but the lateral measurements of the strain are affected thereby, and unless corrected from the stress-strain relation tend to give too high values. The polarizing and analysing Nicols, used throughout, were made by Ahrens, and are of a high degree of perfection. The arrangements for experimental work are of the usual kind, except that it is necessary to bring both the specimen under observation and the calibrating member into focus on the screen for comparison. We are indebted to Professor Filon, F.R.S., for suggesting an arrangement of lenses whereby this can be accomplished when the distance between the two pieces to be compared is considerable. This allows a much more simple arrangement of apparatus than would be required if both pieces were placed in juxtaposition, and it improves the definition of the projected images. Another matter to which attention may be called is that if the plane faces of the specimen are not placed perpendicularly to the plane polarized beam of light, but have the normals thereto inclined at a small angle θ to the direction of the ray, then the inclination of the path inside the material is $\frac{\theta}{\mu}$ and the change in the distance is $t \sec\frac{\theta}{\mu} - t = \frac{1}{2} t \frac{\theta^2}{\mu^2}$ if θ is small. If θ is taken as 5° and $\mu = 1 \cdot 5$ the change in optical path is $0 \cdot 2$ per

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* "The Stress-strain Properties of Nitro-cellulose and the Law of its Optical Behaviour," by Prof. E. G. Coker, F.R.S., and K. C. Chakko, M.Sc. Trans. Roy. Soc., Phil. Series A, vol. ccxxi, 1920.

cent. It is believed that there is no appreciable experimental error from this cause.

There are probably small changes in the refractive indices due

TABLE 4.

Calibration of Lateral Extensometer.

Distance of Scale from reflecting Mirror, 51¾ ins.

Position of Screw.	Reading of Micrometer Head.	Readings. *a.*	*b.*	*c.*	*d.*	Mean Values of Readings.	Percentage Difference from Mean Average Value.
	Degrees.						
I	50–90	144·9	144·3	144·0		144·4	+0
	140–180	142·0	142·2	142·6		142·3	−1·4
	230–270	144·9	144·2	144·2		144·4	+0
	320–360	144·4	141·8	143·3	142·8	143·1	−0·8
II	50–90	145·2	146·7	144·4	—	145·4	+1·0
	140–180	145·4	143·9	144·5	143·7	144·4	+0
	230–270	144·5	143·8	144·0		144·2	−0
	320–360	148·9	147·2	145·9		147·3	+2
III	320–360	144·0	143·4	142·8	144·1	143·6	−0·5
IV	do.	141·9	142·7	142·9	143·1	142·7	−1·1
V	do.	146·3	145·2	145·1	145·6	145·6	+1·0
		Average value of readings				144·3	
		Total numerical error . . .					7·8
		Mean numerical error . .					0·7=0·5%

to changes of temperature, but as this latter did not vary more than 6° F. while measurement was in progress, the effect is probably insignificant.

Errors due to defects in loading have been avoided as far as possible by adjustment of the stressing apparatus until the optical effects show a high degree of symmetry. Small initial stresses are sometimes found in the material, which latter was in all cases examined before cutting into shape, and only the most perfect pieces were used.

In plane stress, or generalized plane stress, such as is dealt with here, the distribution is completely determined when p , q, θ_p and θ_q are known. The directions are comparatively easy to measure, since a stressed plate in plane polarized light shows dark bands which mark these directions with respect to the principal planes of the polarizer and the analyser. The experimental solution is, therefore, complete and independent so long as the law of optical retardation holds and the lateral strains can be interpreted as linear functions of stress or corrected for the deviations from a linear law.

It may also be noted that the stress distributions obtained in all the various cases examined in this Paper may be directly applied to similar cases in other materials, since the fundamental equation $\nabla^4 \chi = o$ for plane stress in simply connected bodies contains no elastic constants, and the stress components are derived from this function χ in the form of partial differential coefficients, in which the co-ordinates are the independent variables.

Experimental evidence on this point has already been given,* and need not, therefore, be referred to further here.

Stress Distribution in Blocks of Equal Breadth and Depth when subjected to Load over a part of One Edge and supported over the Opposite Edge.

The distribution of stress in finite blocks of rectangular form when subjected to load is of fundamental importance, since the masonry and brick-work structures of the engineer and architect are essentially of this type, with pressures distributed over two opposed faces and generally over the whole area of each face, but in other cases where a great load is to be borne, as in columns, this is concentrated over a part of the upper face of the supporting base.

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* "The Optical Determination of Stress." E. G. Coker, Phil. Mag. 1910.

"Photo-Elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members." E. G. Coker, K. C. Chakko and Y. Satake. Trans. Inst. of Engineers and Shipbuilders in Scotland, 1919.

The earlier experiments described above showed that the stresses at the contact areas are not distributed uniformly over either face, and it is probable that a diminution in the size of the block will not change the essential character of the phenomena, although the distribution may be very different. This is borne out by the appearance presented by a block of square form 1 inch side and $\frac{1}{8}$ inch thick when loaded over the central part of one of its rectangular faces. Fig. 11, Plate 16, shows the appearance of such a block when a total load of 50 lb. is applied over a width of $\frac{1}{4}$ in. by means of a pressure plate of the same material. The colour bands there shown are not true circles, but are somewhat distorted curves passing through the extreme points of the upper block, and there are indications of extreme stress at these end-points, since subsidiary loops of colour appear with these end-points as origins.

In order to find the stress distributions for these cases, the principal stresses and their directions have been measured over so much of the areas of the blocks as is practicable.

As will be observed in the preceding Figure, there are areas neighbouring the upper angles for which there is practically no stress, as a dark field is shown for all angular positions of the plane polarized beam. The light band at the extreme edge appears to be due to a bending effect. In the other parts of the field the isoclinic bands are quite distinct except immediately under the load, where there is some difficulty in defining them. The positions of a sufficient number to determine the lines of principal stress are marked on the left hand side of the accompanying Fig. 12, and from any convenient point of this diagram tangent lines are drawn to the curves and the co-ordinates at the limits of a small square are found from the relation $\delta y = \delta x \times \tan \alpha$, where α is the inclination of the line of stress. Proceeding step by step in this manner, the co-ordinates of the curves of principal stress are found, Table 5, and are plotted on the right hand side of Fig. 12. It will be observed that they bear little resemblance to the case of uniform load applied to a limited portion of a semi-infinite plate, except immediately in the neighbourhood of the applied load. In the lower half of the plate, where observation is more difficult, owing to the smallness of the stress, the lines radiating from the upper contact area bend over and probably meet the lower edge very nearly perpendicularly. The magnitudes of the stresses are also determined by observations of $(p + q)$ and $(p - q)$ and these are shown in Table 6 (page 398), from which it will be remarked that the stress distribution is found at a line one-hundredth of an inch away from the contact area, which is very nearly the limit of approach for the measuring needles. Along this line the directions of principal stress may not be quite perpendicular and parallel to the contour owing to unequal surface strains when two unlike rectangular blocks of the same material are present together, but the observations

FIG. 12.

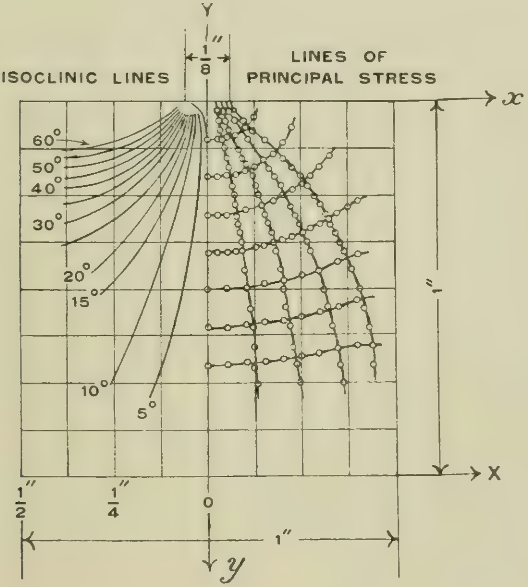


TABLE 5.—*Co-ordinates of Lines of Principal Stress for* 1 *inch* × 1 *inch* × $\frac{1}{4}$ *inch Block with Pressure Face* $\frac{1}{8}$ *inch wide.*

Curves System "A."								Curves System "B."				
X (in.)	Y (inch).							Y (in.)	X (inch).			
0	0·900	0·800	0·700	0·600	0·500	0·400	0·300	0·40	0·115	0·223	0·334	0·427
0·05	0·906	0·804	0·703	0·602	0·502	0·401	0·301	0·45	0·109	0·216	0·322	0·416
0·10	0·930	0·816	0·712	0·608	0·507	0·406	0·304	0·50	0·103	0·206	0·309	0·404
0·15	—	0·844	0·727	0·618	0·514	0·412	0·309	0·55	0·097	0·195	0·293	0·386
0·20	—	0·888	0·749	0·632	0·524	0·420	0·316	0·60	0·090	0·183	0·275	0·365
0·25	—	—	0·783	0·651	0·537	0·431	0·325	0·65	0·083	0·168	0·255	0·343
0·30	—	—	0·829	0·675	0·553	0·442	0·366	0·70	0·076	0·153	0·233	0·316
0·35	—	—	—	0·703	0·573	0·455	0·347	0·75	0·068	0·135	0·208	0·284
0·40	—	—	—	0·737	0·593	0·468	0·356	0·80	0·059	0·115	0·178	0·246
								0·85	0·049	0·092	0·144	0·204
								0·90	0·039	0·069	0·108	0·153
								0·95	0·030	0·049	0·072	0·098

appear to show that the error in taking these lines perpendicular and parallel to the contact surface must be small, while along the remainder of the upper edge these conditions are fulfilled exactly. The distribution of normal stress along this section is therefore shown approximately by the value of p, and, as Table 6 shows, the stress over this contact area is very much concentrated at the ends, as the colour bands indicate. This kind of distribution is obtained when punching a plate, owing to the centre part under the punch bending and forming a cup-shaped depression. The cross stress rises to a maximum at the centre and dies away completely at the ends, in fact changes at 0·01 inch below the surface, so that it seems probable that this distribution of stress is accompanied by a corresponding distribution of shear along the contact surface.

As soon as the distance from the upper plane becomes of the same order as the breadth of the contact surface, the value of q ceases to be of much significance. This is shown by the curves of $(p+q)$ and $(p-q)$, Fig. 13 (page 396), which are nearly identical except within the range indicated above.

In order to obtain the normal stress distribution p_n over planes parallel to the surface, the values of p_n are calculated from the expression—

$$p_n = p \cos^2 \theta + q \sin^2 \theta$$

and are plotted in Fig. 14. These latter curves also permit the accuracy of the measurements to be checked by reference to the load, and with the exception of the last two planes the error is found to be less than ± 5 per cent, as the Table indicates.

On parallel planes more remote from the surface, the minor principal stress rapidly loses any importance and becomes insignificant at distances of more than 0·125 inch from the top surface, until the influence of the distribution at the lower surface is felt. This is indicated by the curves Fig. 13 (page 396), in which the maximum values at intermediate planes tend towards coincidence and then diverge again as the distance increases. Part of this divergence is possibly attributable to experimental error, as there is greater difficulty in determining small stresses optically as compared with large ones, and the presence of small initial stresses is

FIG. 13.

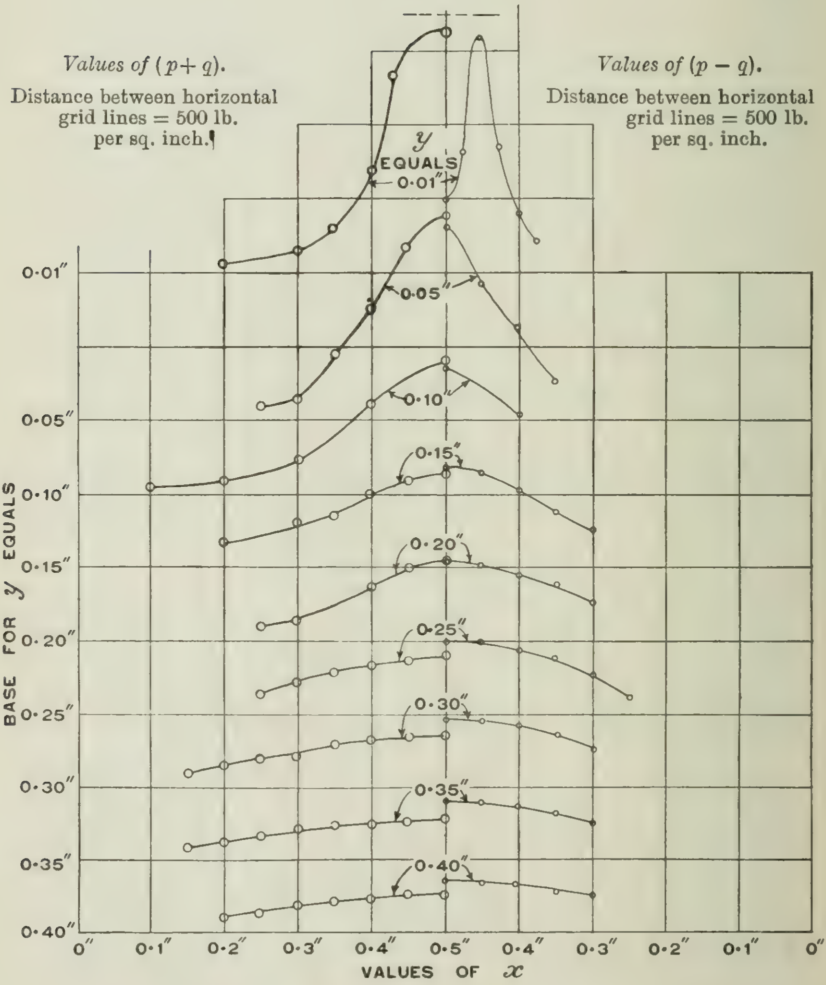

Values of $(p+q)$.
Distance between horizontal grid lines = 500 lb. per sq. inch.
Values of $(p-q)$.
Distance between horizontal grid lines = 500 lb. per sq. inch.
y EQUALS
0·01″
0·05″
0·10″
0·15″
0·20″
0·25″
0·30″
0·35″
0·40″
BASE FOR y EQUALS
0·01″
0·05″
0·10″
0·15″
0·20″
0·25″
0·30″
0·35″
0·40″
0″
0·1″
0·2″
0·3″
0·4″
0·5″
0·4″
0·3″
0·2″
0·1″
0″
VALUES OF x

FIG. 14.—*Values of* P_n.
Distance between horizontal grid lines = 200 lb. per sq. inch.

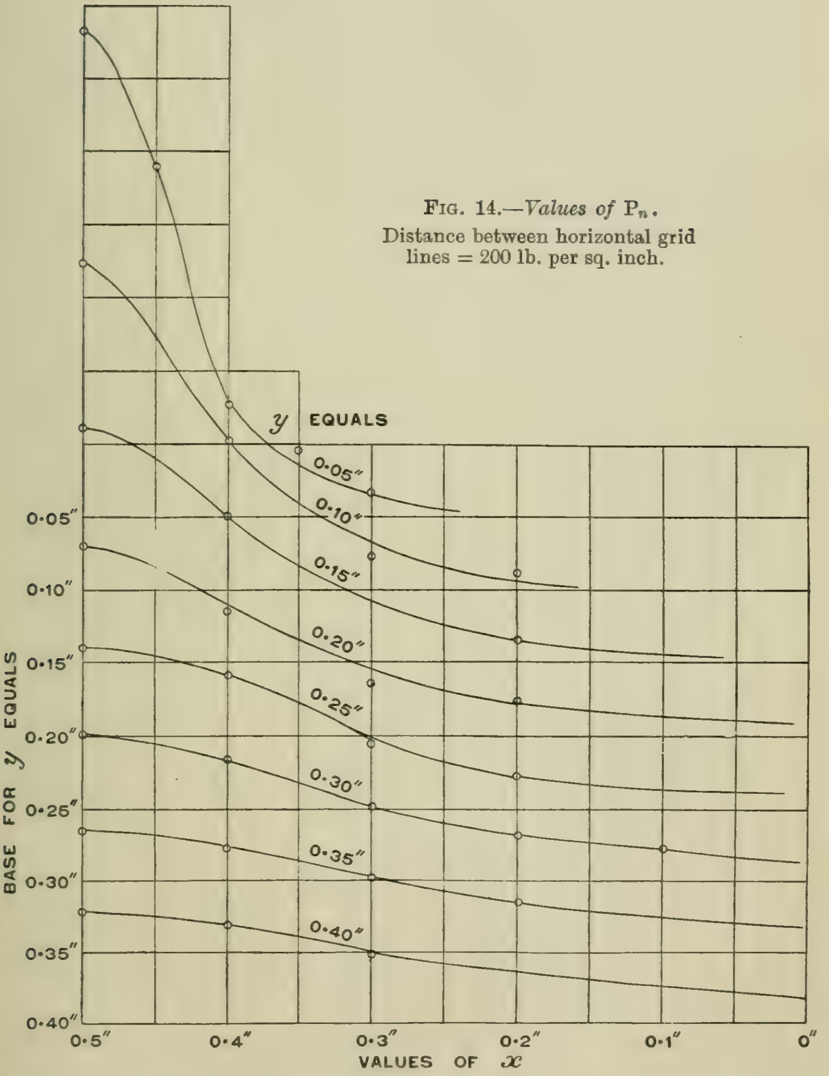


TABLE 6.—*Table of Stresses.*

Actual load 50 lb.

y	x	θ	$p + q$	$p - q$	Cos 2θ	$(p - q) \times$ Cos 2θ	p_n	p_x	Measured Load.	Error.
Inch.	Inch.	Degrees.							lb.	Per cent.
0·01	0·2	—	50	—						
	0·3	—	120	—						
	0·35	—	290	—						
	0·4	—	680	412						
	0·45	—	1,540	1,648						
	0·5	—	1,640	474						
0·05	0·3	—	138	—	—	—	—	—	52·0	4
	0·35	62	425	249	−0·242	−60	183	242		
	0·40	50	721	619	−0·174	−108	307	414		
	0·45	15	1,103	935	0·866	809	956	147		
	0·50	0	1,376	1,289	1·0	1,289	1,332	44		
0·10	0·1	60	40	—	−0·50	—	—	—	50·6	1·2
	0·2	63	90	—	−0·588	—	—	—		
	0·3	57	210	—	−0·407	—	—	—		
	0·4	33	590	556	0·407	226	407	183		
	0·5	0	900	876	1·0	876	888	12		
0·15	0·1	50	—	—	—	—	—	—	49·1	−1·8
	0·2	53	112	—	−0·276	—	—	—		
	0·3	45	289	242	0	0	144	—		
	0·4	25	483	530	0·643	311	412	71		
	0·5	0	628	657	1·0	657	643	−15		

0·20	0·1	40	—	—	—	—	—	—	47·8	−4·3
	0·2	43	—	—	—	—	—	—		
	0·3	35	190	245	0·342	84	136	54		
	0·4	19	344	420	0·788	330	337	7		
	0·5	0	509	520	1·0	520	515	−6		
0·25	0·1	35	—	—	—	—	—	—	48·2	−3·6
	0·2	36	80	—	0·309	—	—	—		
	0·3	27	204	244	0 588	144	174	30		
	0·4	14	346	414	0·883	365	356	−10		
	0·5	0	390	485	1·0	485	438	−48		
0.30	0·1	31	90	—	0·469	—	—	—	48·4	−3·2
	0·2	30	175	—	0·50	—	—	—		
	0·3	22	213	249	0·719	179	196	17		
	0·4	11	299	398	0·922	368	333	−34		
	0·5	0	341	450	1·0	450	396	−55		
0·35	0·1	28	75	—	0·559	—	—	—	47·3	−5·4
	0·2	25	150	—	0·643	—	—	—		
	0·3	19	204	249	0·788	194	199	5		
	0·4	10	239	350	0·940	329	284	−45		
	0·5	0	272	387	1·0	387	330	−58		
0·40	0·1	23	50	—	0·695	—	—	—	46·9	−6·2
	0·2	22	112	—	0·719	—	—	—		
	0·3	16	176	248	0·848	210	193	−17		
	0·4	8	228	320	0·961	308	268	−40		
	0·5	0	255	350	1·0	350	302	−47		

TABLE 7.—*Co-ordinates of Lines of Principal Stress for 1 inch × 1 inch × $\frac{1}{4}$ inch Block with Pressure Face $\frac{1}{4}$ inch wide.*

Curves System "A."							Curves System "B."				
X (in.)	Y (inch).						Y (in.)	X (inch).			
0	0·900	0·800	0·700	0·600	0·500	0·400	0·40	0·113	0·239	0·336	0·411
0·05	0·902	0·802	0·702	0·601	0·501	0·401	0·45	0·110	0·229	0·325	0·404
0·10	0·912	0·812	0·708	0·605	0·504	0·403	0·50	0·105	0·219	0·313	0·396
0·15	0·937	0·831	0·721	0·614	0·509	0·407	0·55	0·100	0·208	0·300	0·382
0·20	—	0·860	0·739	0·626	0·518	0·414	0·60	0·095	0·196	0·285	0·367
0·25	—	0·914	0·764	0·642	0·529	0·422	0·65	0·089	0·182	0·268	0·348
0·30	—	—	0·797	0·662	0·543	0·433	0·70	0·082	0·166	0·248	0·326
0·35	—	—	0·845	0·684	0·558	0·443	0·75	0·075	0·150	0·225	0·300
0·40	—	—	—	0·707	0·573	0·453	0·80	0·067	0·132	0·199	0·268
0·45	—	—	—	—	—	0·458	0·85	0·059	0·113	0·171	0·229
0·50	—	—	—	—	—	0·460	0·90	0·053	0·097	0·143	0·186
							0·95	0·050	0·085	0·118	0·140

more noticeable. The observations in fact agree very well with the load applied for planes near the upper surface, as the error column of Table 6 shows, but at the extreme planes of observations the error becomes comparatively large.

To obtain further evidence on these matters, the load was increased and distributed over a correspondingly greater width of $\frac{1}{4}$ inch as shown in Fig. 15 to prevent the local failure of the material. In this latter case, the non-uniform character of the load distribution is very marked, as the observations at $y=0{\cdot}02$ inch show (Figs. 16 and 17 and Table 8). At the centre the normal stress is rather more than 1,100 lb. per square inch and rises to nearly 1,500 lb. per square inch immediately under the extreme edge of the upper pressure plate, while there is a cross stress of about 525 lb. per square inch at the centre, which diminishes to zero and changes sign very abruptly in the neighbourhood of this maximum normal stress. Effects of

FIG. 15.

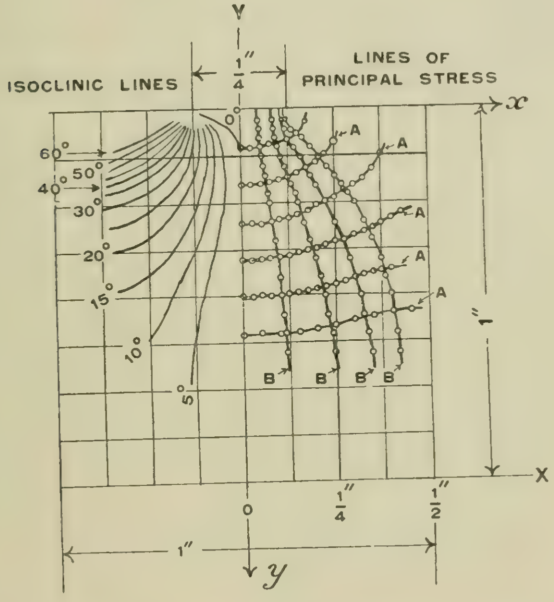
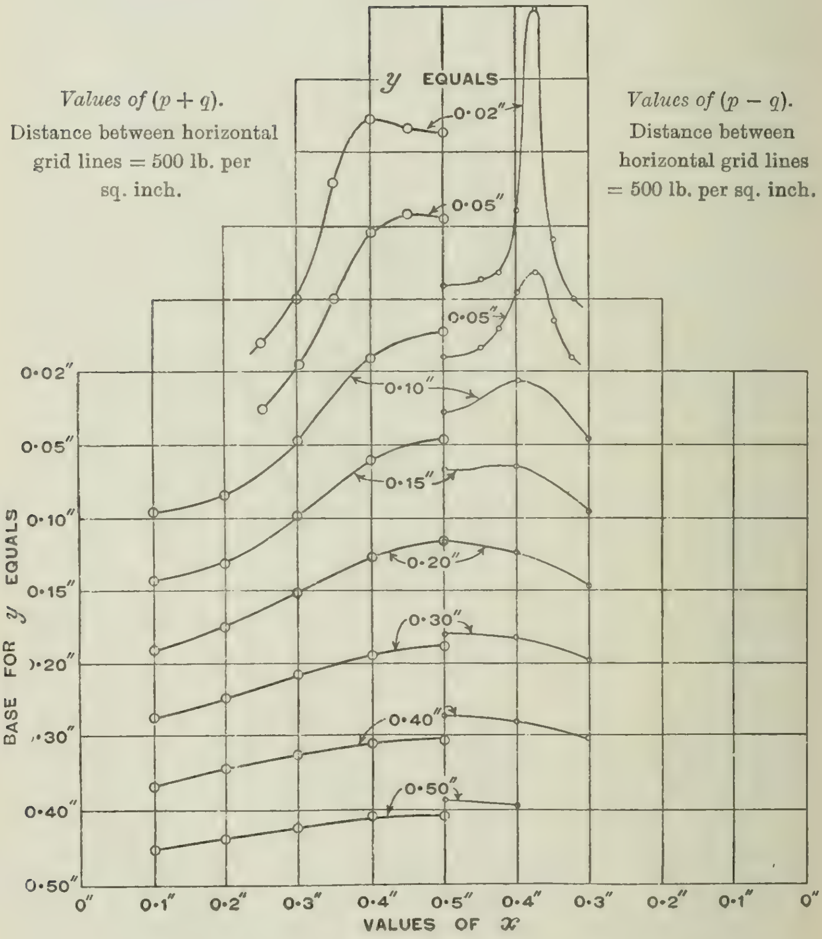


FIG. 16.



Values of $(p+q)$.
Distance between horizontal grid lines = 500 lb. per sq. inch.

Values of $(p-q)$.
Distance between horizontal grid lines = 500 lb. per sq. inch.

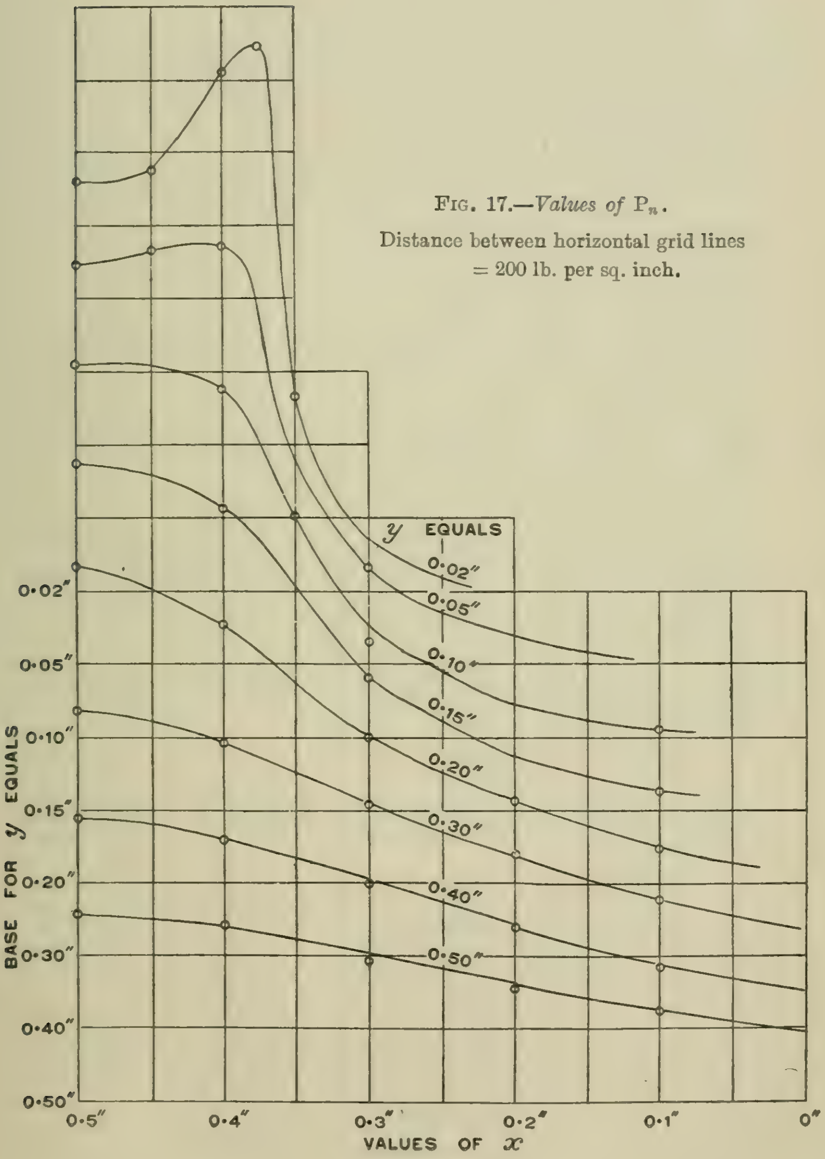


FIG. 17.—*Values of* P_n.

Distance between horizontal grid lines = 200 lb. per sq. inch.

TABLE 8.—*Table of Stresses*

Actual Load 100 lb.

y	x	θ	$p+q$	$p-q$	Cos 2θ	$(p-q)\times$ Cos 2θ	p_y	p_x	Measured Load.	Error.
Inch.	Inch.	Degrees.							lb.	Per cent.
0·02	0·3	75	475	412 (?)	−0·866	−357	59	416	100·65	0·65
	0·35	55	1,400	927	−0·342	−317	541	859		
	0·375	30	1,675	2,575	+0·500	1,287	1,481	194		
	0·40	10	1,750	1,133	0·940	1,071	1,410	340		
	0·45	0	1,680	628	1·000	628	1,154	526		
	0·50	0	1,650	598	1·000	598	1,124	526		
0·05	0·25	70	240	—	−0·766	—	—	—	98·4	−1·6
	0·3	60	545	—	−0·5	—	—	—		
	0·35	50	1,000	955	−0·174	−167	416	584		
	0·4	20	1,450	1,056	0·766	809	1,127	323		
	0·45	2	1,560	679	0·998	679	1,120	440		
	0·5	0	1,550	618	1·000	618	1,084	466		
0·10	0·1	65	48	—	−0·643	—	—	—	94·5	−5·5
	0·2	60	180	—	—0·5	—	—	—		
	0·3	45	565	546	0	0	282	283		
	0·4	17	1,100	948	0·829	788	944	156		
	0·5	0	1,270	742	1·000	742	1,006	264		

0·15	0·1	55	90	—	−0·342	—	—	—	95·7	−4·3
	0·2	48	220	—	−0·105	—	—	—		
	0·3	35	530	530	0·342	186	358	172		
	0·4	16	905	850	0·848	744	825	80		
	0·5	0	1,040	845	1·0	845	942	98		
0·20	0·1	30	95	—	0·5	—	—	—	95·8	−4·2
	0·2	30	250	—	0·5	—	—	—		
	0·3	28	490	530	0·559	305	398	92		
	0·4	15	730	760	0·866	678	704	26		
	0·5	0	840	875	1·0	875	858	−18		
0·30	0·1	25	150	—	0·643	—	—	—	92·3	−7·7
	0·2	25	285	—	0·643	—	—	—		
	0·3	21	440	495	0·743	379	410	30		
	0·4	11	550	648	0·927	618	584	−34		
	0·5	0	610	721	1·0	721	666	−56		
0·40	0·1	18	170	—	0·809	—	—	—	90·3	−9·7
	0·2	18	278	—	0·809	—	—	—		
	0·3	15	365	475	0·866	423	394	−29		
	0·4	7	440	595	0·970	595	518	−78		
	0·5	0	475	670	1·0	670	572	−97		
0·50	0·1	14	240	—	0·883	—	—	—	93·9	−6·1
	0·2	14	310	—	0·883	—	—	—		
	0·3	11	390	—	0·927	—	—	—		
	0·4	5	435	525	0·985	534	485	−50		
	0·5	0	450	577	1·0	577	513	−63		

the same general character are observed up to a distance of nearly 0·1 inch from the edge, but from this distance onwards both $(p+q)$ and $(p-q)$ have maximum values at the central section. All the observations, in fact, go to show a distribution of load which is far from uniform both at the upper and lower surfaces of the block, while the stress conditions which obtain in the interior are largely conditioned by these and the proximity of the sides.

DISTRIBUTION OF STRESS IN BLOCKS LOADED OVER THE WHOLE EXTENT OF THEIR UPPER AND LOWER SURFACES.

The importance of this type of loading has been noted earlier, and the cases already examined naturally lead to the inquiry whether it is possible to so load a short rectangular block as to produce uniform compression throughout. It is sometimes assumed, where a central load is applied to the ends of such a block, by thick distributing plates such as are usual in most forms of testing machines, that it is uniformly stressed throughout, but this is not usually the case, for if the materials pressed together are of a different nature, the stress distribution is apparently always non-uniform, no matter how well the faces may be prepared. This is illustrated by the case of a square block pressed between brass plates, which shows zones of non-uniform stress at the ends which only disappear when the distance from the contact surface is appreciable. The pressure between these dissimilar materials apparently gives rise to considerable tangential stress at the common boundary and lateral expansion is prevented. If, however, a very extensible material, such as a thin sheet of rubber, is interposed, the tangential stress is reversed and the lateral strains become abnormally great, especially near the central vertical section ; they are, however, fairly uniform throughout the depth. The tangential forces over the end boundaries produce considerable tensional stresses in the material in the direction of the thickness of the plates. This disruptive effect has been frequently observed in compression tests of stone blocks, when the faces under load are covered by thin sheets of lead.* The experimental evidence, therefore, goes to show that in order to obtain pure compression stress in a block the contact faces must be similar and equal, and of the same material. These conditions are approximately fulfilled by interposing similar end plates of sufficient length, as may be shown in the polariscope when a square is compressed between two plates of like material and of the same cross section. When loaded in this manner an approximately pure compression stress is obtained, but even with these precautions it may not be perfect, as the experimental analysis of Table 9 (page 413) shows. With a total load of 260 lb., corresponding to a mean stress of 1,030 lb. per square inch, there is nearly pure compression stress at the upper and lower bounding surfaces, although not quite uniform, as the plotted values of Fig. 18 indicate. The cross stress q is insignificant, but towards the centre this latter becomes an appreciable tension, and has an approximately parabolic distribution as the Figure shows, with a maximum value at the centre of the block of rather more than 5 per cent of the numerical value of the applied pressure.

A block of one-half this depth gives rather better results, and when loaded in this manner almost perfectly pure compression stress is obtained.

THE INFLUENCE OF CONTACT STRESSES IN THE TESTING OF MATERIALS.

It is a well-known and often disconcerting circumstance in experiments on the tensile strength of materials, that metal bars and rods often fracture at the gauge-points or even outside these limits, especially in hard materials. The reasons for the latter type of fracture have been examined recently,† but so far as the Authors are aware the exact effect of the minute indentations required for the attachment of extensometers has not been examined. Although fractures at the gauge-points are frequent in unyielding material,

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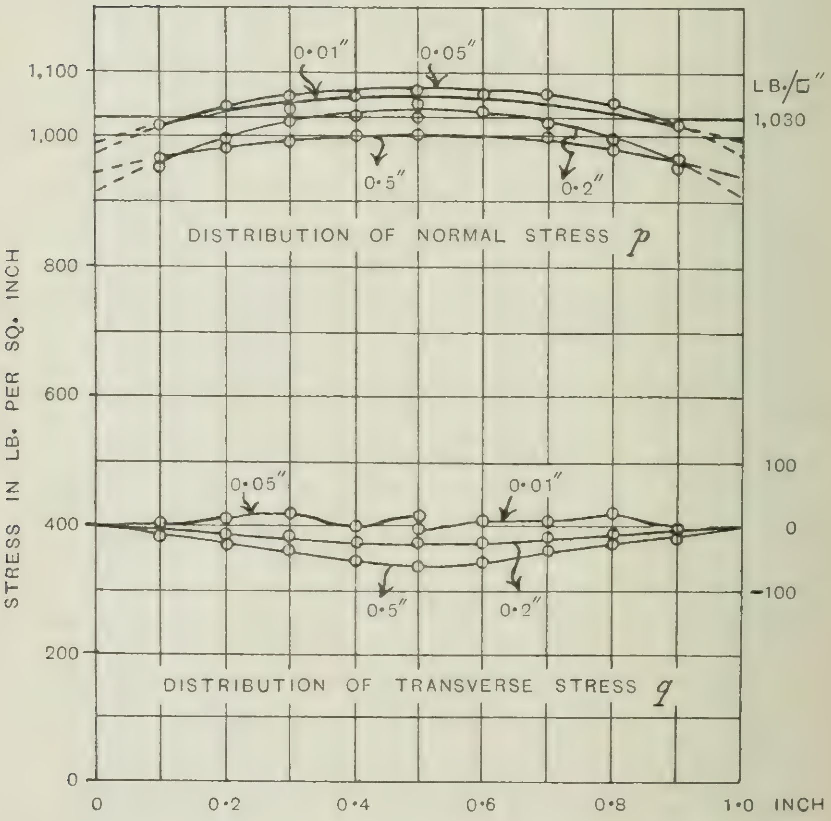
* "The Testing of Materials." W. C. Unwin, F.R.S. 1st edition, page 417.

† "Photo-Elastic Measurements of the Stress Distribution in Tension Members used in the Testing of Materials." E. G. Coker, Proc., Inst.C.E., vol ccviii, Part ii, 1918–19.

Fig. 18.—*Pressure Distribution in* 1 *inch* × 1 *inch* × 0·254 *inch Block with Secondary Pressure Plates* 0·4 *inch deep.*

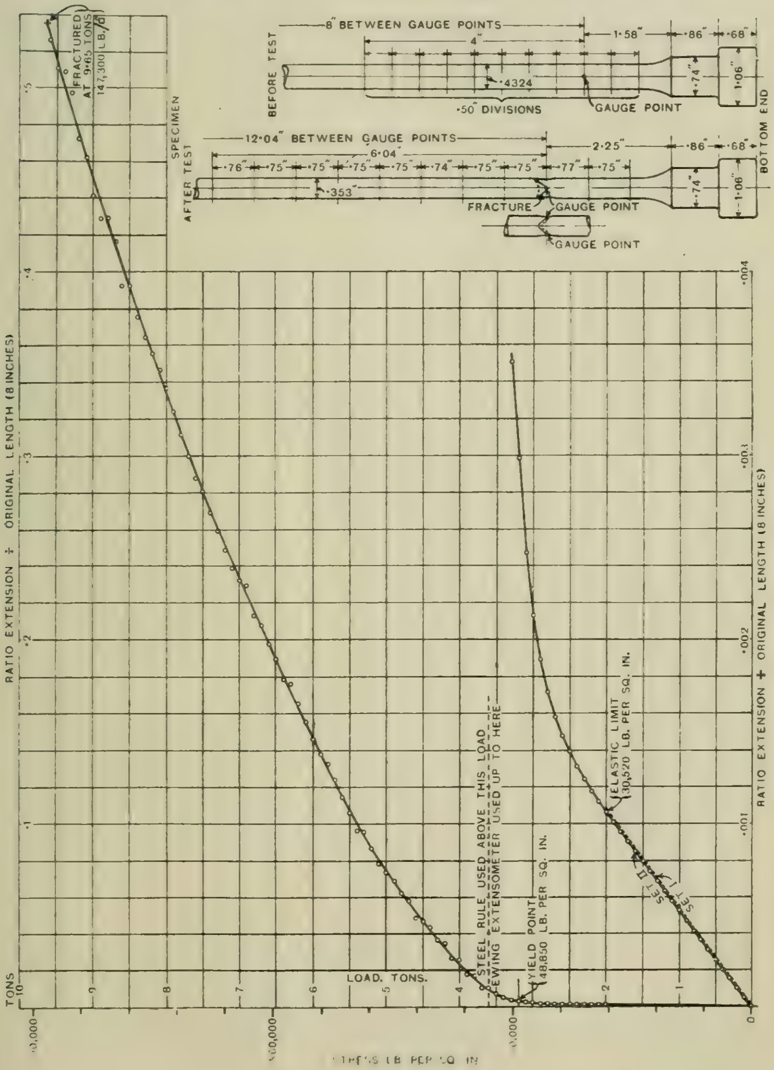
Load Applied 260 lb.



they also occur in cases where the substance becomes very plastic, and this is well shown by a specimen of forged manganese steel kindly sent by Sir Robert Hadfield for examination. This specimen was in the form of a round bar with enlarged ends, Fig. 19, machined to fit the shackles of a 10-ton Buckton testing-machine

FIG. 19.—*Hadfield's Test-Bar, A*8725.

Initial Condition of Specimen: Surface finished smooth by grinding.



at University College. Owing to the high tensile strength of the material, it was found necessary to make the specimen of rather small diameter, in order to carry the test to completion. The salient features of the test are recorded in Fig. 19 of the load extension diagram, from which it appears that this material has a high elastic limit and yield-point, and a great capacity in the plastic condition for stretching under load, coupled with a very high ultimate stress. The remarkable quality of this material is indicated by the data obtained, from which it will be observed that

Data of Fig. 19 (page 409).

——	Initial.	Final.
	Inches.	Inches.
Distance between Gauge-Points . .	8·00	12·04
Mean Diameter	0·4324	0·3532
Modulus . . (between 0·2 and 1·0 ton)	$28\cdot5 \times 10^{6}$ = lb. per sq. inch	
Elastic Limit . . . . (2 tons)	30,520 lb. per sq. inch	
First Yield-Point . . . (3·2 tons)	48,850 lb. per sq. inch	
Breaking Stress . . . 9·65 tons)	147,300 lb. per sq. inch	
Equivalent Elongation in 8 ins. . (4·08 ins.)	51 per cent	
Minimum Diameter at Fracture . .	0·323 inch	
Reduction in Area	43 per cent	
Ultimate Stress at Minimum Section away from Point of Fracture. (Diam. 0·35 in.)	224,650 lb. per sq. inch	
Character of Fracture .	Fibrous with silky lustre.	
Place of Fracture . .	Lower Gauge-Points.	
Temperature of Laboratory	55° F.	
Date of Test . . .	1st April 1920	

the total elongation at fracture, measured on an 8-inch length, amounted to 51 per cent, and was, moreover, distributed very uniformly throughout its length, as the Figure shows. The specimen broke at a load of 9·65 tons, corresponding to a stress of 147,300 lb. per square inch of the original section and 224,650 lb. per square inch of the actual section at fracture, which latter occurred at a gauge-point, although every care possible was taken to avoid this by using very minute centres for the support of the Ewing extensometer employed.

The test, therefore, does not show the true strength of the material at fracture, owing to the effect of the small indentations, causing a break at a definite place fixed by the conditions imposed by the test. It is also possible that the cross-sectional area at fracture is affected by the same cause.

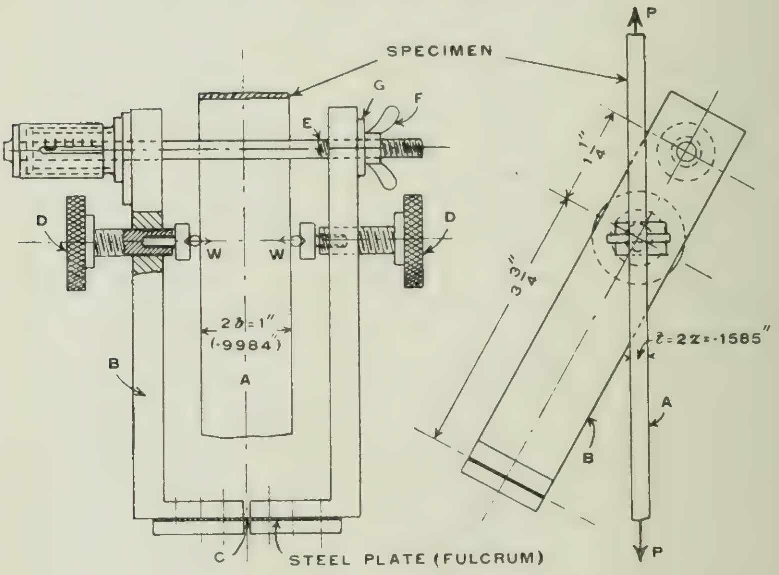
This example is typical of the general difficulty which occurs in this kind of testing, and it has led to various devices for avoiding indentations or scratches in test-pieces. The problem, in fact, presents a case of contact stress of practical importance, which appears to warrant further investigation, in order to ascertain the changes in stress distribution caused by various methods used in determining the tensile strength of materials. A form of gripping device to imitate the action of point or line grips was therefore constructed, in which the pressure, applied laterally, could be measured. This consisted of a U-shaped frame, shown in side and end elevation, Fig. 20, to grip a tension member A. The frame B is made in two parts connected by a thin steel plate fulcrum C, and at a convenient distance from this latter there are a pair of adjustable screws D, the inner ends of which are bored out to receive various types of gripping devices. Those shown in the Figure are small cylindrical steel pins, but others were also used, such as knife-edges, cylinders and flat plates of various widths.

A measurable load is applied to the grips by a rod E screwed at one end and furnished with an adjustable nut F bearing against a pivoted washer G to ensure axial loading. At the opposite end, the rod E is attached to a calibrating spring, the compression of which measures the applied load, while a micrometer scale, not shown on the diagram, indicates when the long arms of the frame B are exactly parallel, and therefore producing oppositely directed loads. For convenience the holes in the frame B are arranged so that the screws D and the load measuring device E, F, G, can be interchanged to give a greater range for experiment. The weight of the gripping device is also balanced by counterpoise weights applied to the screws D.

Fig. 20.—*Loading Arrangement.*

Dimensions of Specimen . .	0·9984 inch × 0·1585 inch.
Comparison Test-piece . .	0·3750 inch × 0·1573 inch.

Thickness assumed for Calculation of Stresses (Standard) 0·1 inch.
Width of Specimen taken as 1·000 inch.

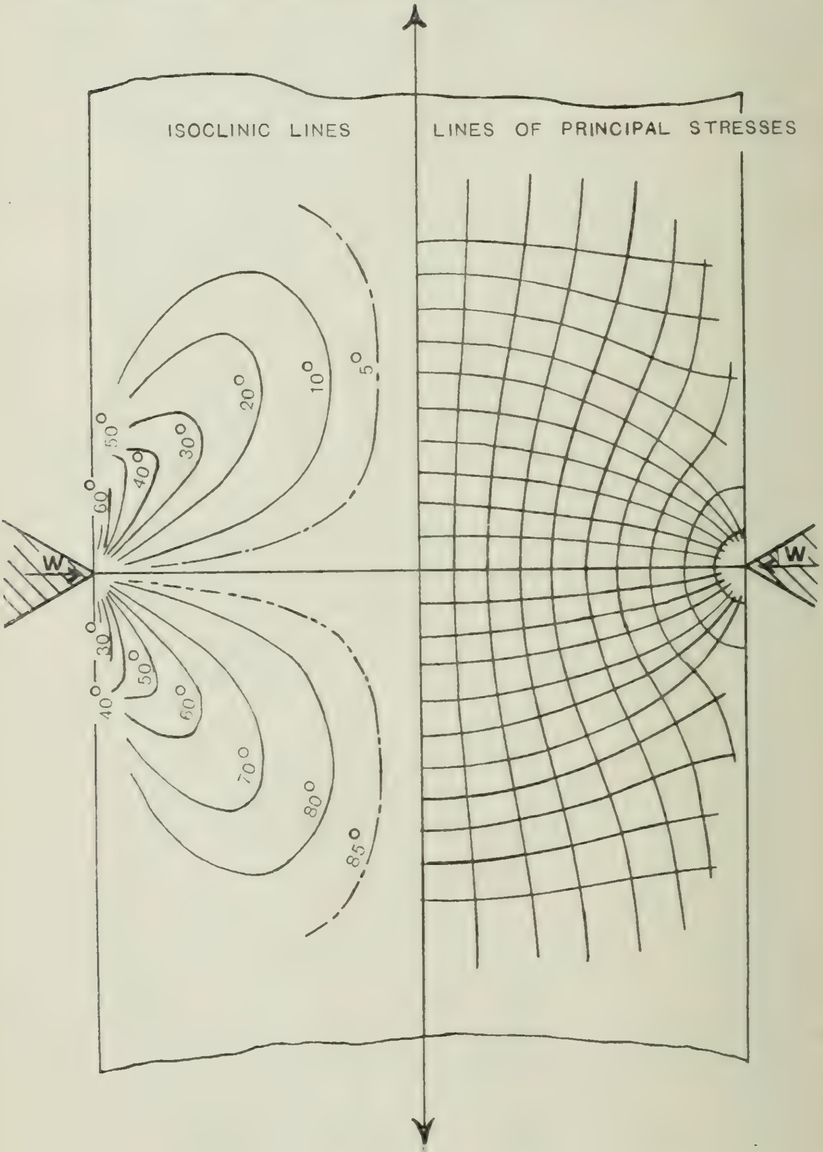


The lateral loads due to screw points gripping the specimens not only injure the specimen and often determine the place of fracture, but they may also change the stress distribution, and this is well shown in Fig. 21 (page 414), in which lateral pressures of 15 lb., applied by knife-edges having an angle of 60°, change the

TABLE 9.—*Measurements on* 1 *inch* × 1 *inch* × 0·252 *inch Block with Secondary Pressure Plates* 0·4 *inch deep. Applied Load* 260 *lb.*

y	x	θ	$p+q$	$p-q$	p	q	Measured Load.	Error.
In.	In.	Degs.	lb.	lb.	lb.	lb.	lb.	Per cent.
0·01	0·1	0	1,001	1,027	1,014	−13	262·5	+1·0
	0·2	,,	1,069	1,038	1,054	+16		
	0·3	,,	1,042	1,038	1,040	+ 2		
	0·4	,,	1,069	1,060	1,065	+ 5		
	0·5	,,	1,050	1,060	1,055	− 5		
0·02	0·1	0	990	1,027	1,009	−19	262·9	+1·1
	0·2	,,	1,075	1,038	1,057	+19		
	0·3	,,	1,077	1,088	1,058	+20		
	0·4	,,	1,068	1,060	1,064	+ 4		
	0·5	,,	1,036	1,060	1,048	−12		
0·05	0·1	0	1,020	1,016	1,018	+ 2	263·0	+1·2
	0·2	,,	1,042	1,027	1,035	+ 8		
	0·3	,,	1,089	1,038	1,064	+26		
	0·4	,,	1,045	1,060	1,053	− 8		
	0·5	,,	1,084	1,060	1,072	+12		
0·10	0·1	0	912	1,006	959	−47	253·4	−2·6
	0·2	,,	1,012	1,016	1,014	− 2		
	0·3	,,	1,062	1,038	1,050	−38		
	0·4	,,	1,054	1,060	1,057	− 3		
	0·5	,,	1,035	1,060	1,048	−13		
0·20	0·1	0	111	995	953	−42	253·3	−2·6
	0·2	,,	960	1,016	988	−28		
	0·3	,,	1,001	1,038	1,020	−19		
	0·4	,,	1,004	1,060	1,032	−28		
	0·5	,,	1,046	1,060	1,053	−27		
0·30	0·1	0	917	995	956	−39	248·3	−4·5
	0·2	,,	948	1,006	977	−29		
	0·3	,,	969	1,038	1,004	−35		
	0·4	,,	1,007	1,060	1,034	−27		
	0·5	,,	1,012	1,060	1,036	−24		
0·40	0·1	0	906	984	945	−39	248·0	−4·6
	0·2	,,	923	1,006	970	−42		
	0·3	,,	957	1,038	998	−41		
	0·4	,,	964	1,060	1,012	−48		
	0·5	,,	960	1,060	1,010	−50		
0·50	0·1	0	938	984	961	−23	248·0	−4·6
	0·2	,,	942	1,006	974	−32		
	0·3	,,	942	1,038	990	−38		
	0·4	,,	942	1,060	1,001	−59		
	0·5	,,	929	1,060	995	−66		

FIG. 21.—*Isoclinic Lines and Lines of Principal stresses in a Tension Member.*

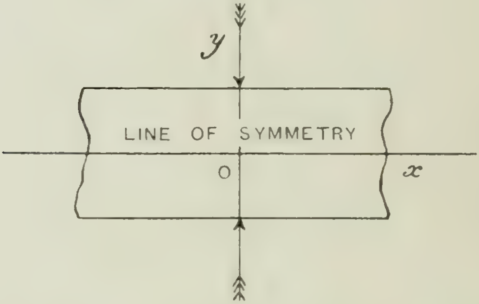


character of a simple tension stress due to a total load of 45 lb. into a distribution of considerable complexity. In this case the lines of equal inclination, determined experimentally, are shown on the left-hand side, and from these are drawn the orthogonal curves of principal stress. In a simple tension test, these lines should be parallel and perpendicular to the straight contours of the specimen, and the actual lines show how very great is the change in the type of stress due to the lateral pinch, and demonstrate that simple tensional stress is only regained at an axial distance from the loading of rather more than half the width of the bar. The experimental values in this case are important as indicating the character of the disturbance in the stress conditions, and why failure is likely to occur at the section under the combined effects of the lateral stress due to a permanent indentation combined with longitudinal pull.

The results obtained encouraged the Authors to proceed further with this part of the investigation, and it was resolved to measure the distributions obtained with various forms of contacts applied laterally to the bar, especially as a cylindrical roller contact had been found very useful in testing the mechanical properties of thin strip steel, used for aeroplane structures during the war. Such material is especially difficult to test, as a scratch or indentation generally determines the place of fracture. In order, therefore, to measure the extension of the material, an arrangement was devised which was found to work satisfactorily. Clips were provided, on the inner sides of which were slots containing cylindrical pins, housed so that they projected a very slight amount beyond the inner faces of each member of the clip, and these pins were pressed against the specimen when the clips were drawn together by small bolts. This arrangement gave a sufficient grip to support an extensometer from the clips without injuring the material, and in practice the strip broke within the gauge length. In the testing of nitro-cellulose, narrow blocks, cemented to the edges of a strip, have been employed instead of clips, and this latter arrangement also proved fairly successful.

An examination of the essential features of both these forms was carried out, therefore, and compared with some calculations, which are fortunately available. Prof. Filon has shown * that the stress produced by oppositely directed forces applied perpendicularly to the sides of a rectangular strip, of breadth $2b$, can be evaluated, and he obtains for the stresses the following values :—

FIG. 22.



$$\widehat{xx} = -\frac{2W}{\pi b}\int_0^\infty \frac{\sinh u - u\cdot\cosh u}{\sinh 2u + 2u}\cdot\cos\frac{ux}{b}\cdot\cosh\frac{uy}{b}\cdot du$$

$$-\frac{2W}{\pi b}\int_0^\infty \frac{uy}{b}\cdot\frac{\sinh u}{\sinh 2u + 2u}\cdot\cos\frac{ux}{b}\cdot\sinh\frac{uy}{b}\cdot du$$

$$\widehat{yy} = -\frac{2W}{\pi b}\int_0^\infty \frac{\sinh u + u\cosh u}{\sinh 2u + 2u}\cdot\cos\frac{ux}{b}\cdot\cosh\frac{uy}{b}\cdot du$$

$$+\frac{2W}{\pi b}\cdot\int_0^\infty \frac{u\sinh u}{\sinh 2u + 2u}\cdot\cos\frac{ux}{b}\cdot\sinh\frac{uy}{b}\cdot du$$

$$\widehat{xy} = \frac{2W}{\pi b}\int_0^\infty \frac{u\cdot\cosh u}{\sinh 2u + 2u}\cdot\sin\frac{ux}{b}\cdot\sinh\frac{uy}{b}\,du$$

$$-\frac{Wy}{\pi b^2}\int_0^\infty \frac{u\sinh u}{\sinh 2u + 2u}\cdot\sin\frac{ux}{b}\cdot\cosh\frac{uy}{b}\cdot du.$$

The numerical values of the stresses along the axes of symmetry have been obtained, although with much labour, for the case where

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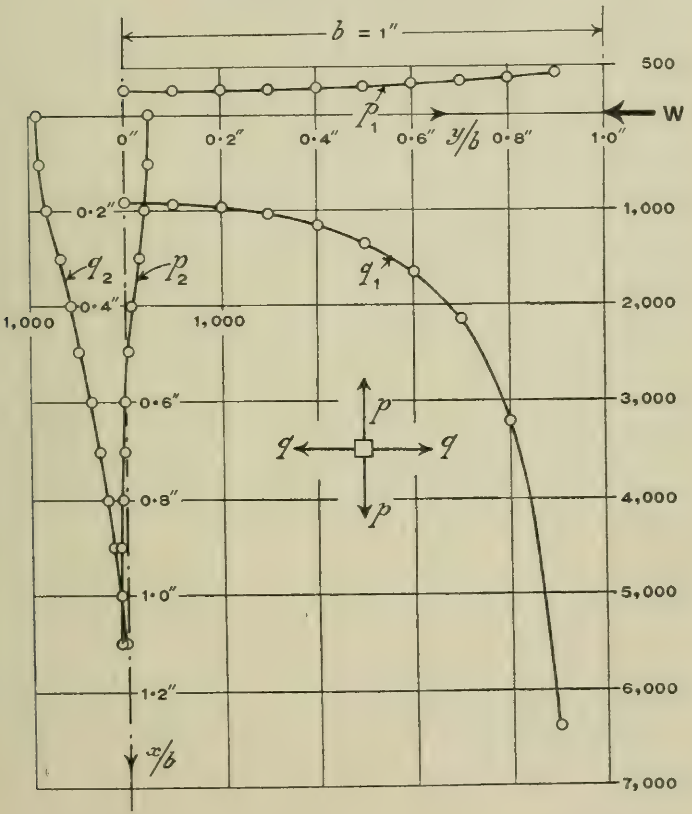
* *Loc. cit.*, ante p. 18.

$W = 100$ lb., $2b = 1$ inch, and the thickness of the strip is $\frac{1}{16}$ inch, and their values are recorded in the accompanying Table 10 (page 418) for comparison purposes. It may be remarked in passing that these numerical values were found to agree with some given in the Paper

Fig. 23.—*Theoretical Results.*



already cited, but the Authors were obliged to extend the range to suit the particular purpose, while for convenience of calculation the values of p and q were obtained from the more convenient expressions of the sums and differences of the principal stresses.

Thus for $\frac{y}{b} = o$ the formulæ above give

$$p_2 + q_2 = -\frac{4\,\mathrm{W}}{\pi b} \cdot \int_o^\infty \frac{\sinh u}{\sinh 2u + 2u} \cdot \cos \frac{ux}{b} \cdot du$$

$$p_2 - q_2 = +\frac{4\,\mathrm{W}}{\pi b} \cdot \int_o^\infty \frac{u \cosh u}{\sinh 2u + 2u} \cdot \cos \frac{ux}{b} \cdot du$$

with expressions of a similar type for $(p_1 \pm q_1)$.

TABLE 10.

Data.

Breadth . . . $2b = 2$ inches.
Thickness . . . $t = 2z = 0{\cdot}1$ inch.
Pull . . . . $\mathrm{P} = 0$.
Pressure . . . $\mathrm{W} = 100$ lb.

Stresses along $\frac{x}{b} = 0$.

$\frac{y}{b}$	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
p_1	249	252	257	264	279	292	319	347	388	431
q_1	−920	−933	−972	−1046	−1166	−1341	−1647	−2150	−3200	−6370

Stresses alone Line $\frac{y}{b} = 0$.

$\frac{x}{b}$	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1
p_2	249	236	202	153	65	45	−4	−37	−63	−74	−81	−82
q_2	−920	−895	−830	−670	−586	−501	−388	−289	−205	−142	−93	−55

The values so obtained are plotted for convenient reference in Fig. 23 for comparison with the cases selected.

It will be observed that p is small along either axis and the labour of separating p and q is hardly justified, so that we are content to compare, in all cases, the optical values of stress distribution with

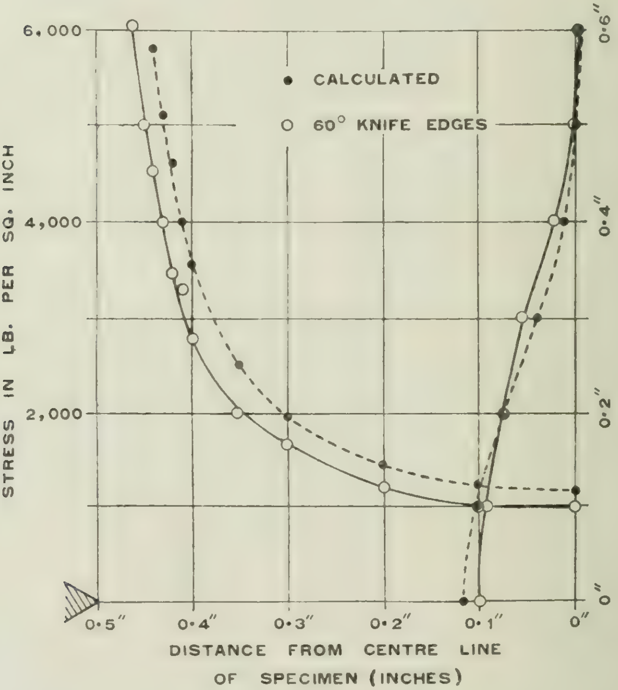
TABLE 11.

Table of $(p - q)$ *Values*).

		Calculated.	60 deg. knife edge.	Flat.			Round Pin.			
				Width $\frac{1}{20}$ in.	Width $\frac{1}{8}$ in.	Width $\frac{1}{4}$ in.	Diam. $\frac{1}{16}$ in.	Diam. $\frac{1}{8}$ in.	Diam. $\frac{3}{16}$ in.	Diam. $\frac{1}{4}$ in.
$\frac{x}{b} = 0$ $\frac{y}{b} =$	0·0	2,340	1,990	2,150	2,410	1,970	2,120	2,170	2,150	2,150
	0·2	2,460	1,960	2,200	2,490	2,075	2,260	2,160	2,150	1,320
	0·4	2,890	2,380	2,690	2,950	2,280	2,440	2,270	2,280	2,560
	0·6	3,930	3,290	3,520	3,815	2,560	3,460	3,370	2,580	3,400
	0·7	4,994	3,980	4,640	5,270	2,840	4,350	4,040	3,900	4,560
	0·8	7,116	5,510	7,140	6,065	2,800	6,880	6,720	5,920	7,240
	0·84	9,200	6,930	9,040	6,365	2,650	9,340	8,300	7,910	9,060
	0·88	11,600	8,530	14,000	6,165	1,880	12,840	11,100	13,080	10,920
	0·90	13,600	9,960	15,700	5,220	1,650	15,300	13,240	14,600	12,600
	0·92	—	12,100	18,200	4,450	1,370	—	15,400	—	15,880
	0·94	—	18,300	—	4,050	930	—	—	—	—
	0·96	—	23,800	—	—	825	—	—	—	—
	0·98	—	—	—	—	—	—	—	—	—
$\frac{y}{b} = 0$ $\frac{x}{b} =$	0·0	2,340	1,990	2,100	2,420	1,995	2,120	2,170	2,150	2,150
	0·2	2,064	1,814	1,820	2,350	1,720	1,620	1,680	1,880	1,880
	0·4	1,302	1,460	1,200	1,540	1,320	1,300	1,060	1,100	1,440
	0·6	768	1,100	440	830	610	800	740	530	1,040
	0·8	284	427	300	300	320	290	400	210	230
	1·0	24	0	20	20	40	60	60	60	40
	1·2	−120	−107	−20	−130	−150	−80	−120	−100	−110

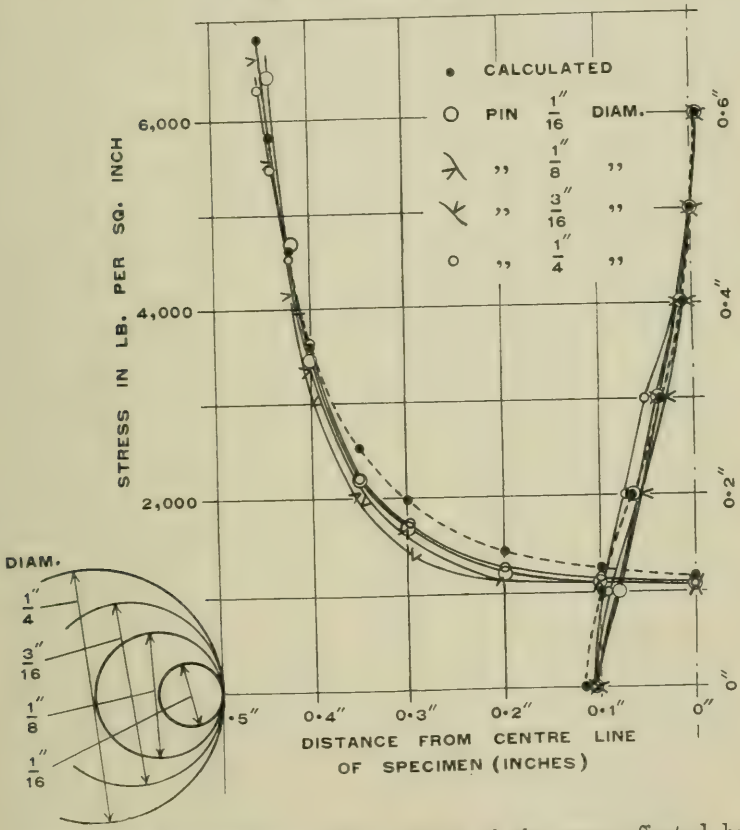
the calculations. All the results so obtained along both axes are recorded in the accompanying Table 11, and are plotted in diagram form to facilitate comparison. The distribution obtained with knife-edges is perhaps the most interesting from a theoretical aspect, since, as Fig. 24 shows, there is a good agreement, especially along the centre line of the member where the stress is small and somewhat difficult to measure. Along the axis of the applied load the agreement is apparently less satisfactory, since all the measured values are less than those obtained from calculation, but the discrepancy is easily explained by a circumstance, already pointed out in the experiments of Carus-Wilson, that the application of pressure along a line by means of a knife-edge causes the latter to

Fig. 24.—*Stresses* $(p-q)$. *Set* 1.



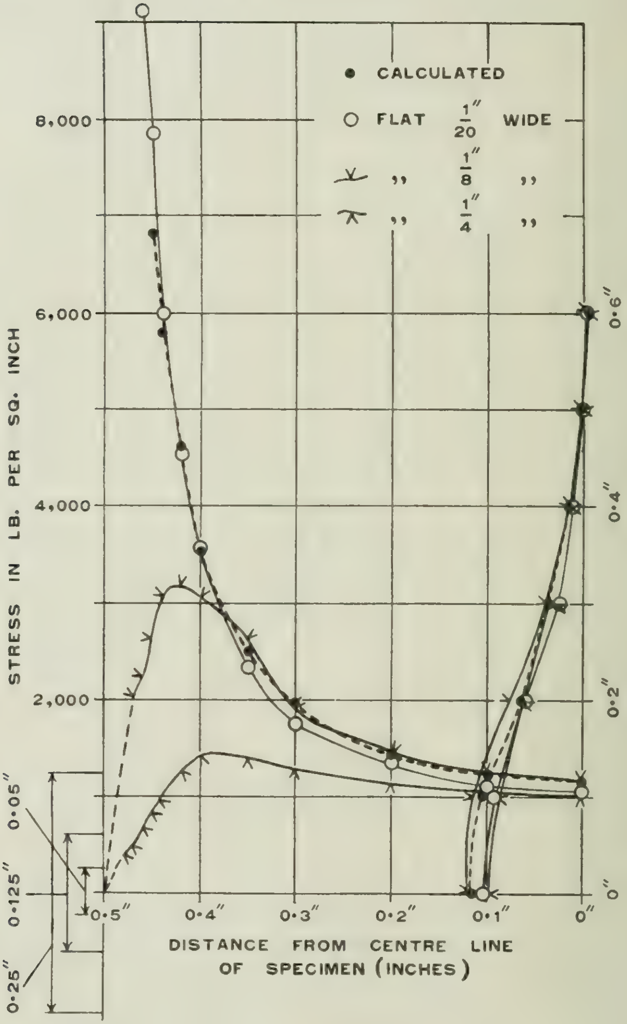
sink into the material, and for a true comparison the experimental curves must be depressed an appreciable amount. With this correction, amounting in this case to $\frac{1}{30}$ inch, the agreement is close and affords a verification, if such were needed, of the accuracy of the analysis. The extent of the area affected by a lateral pinch is indicated by Fig. 25, Plate 17, and the disturbance produced by centres are easily realized from the colour bands.

Fig. 26.—*Stresses* $(p-q)$.



If, instead of a knife-edge, a roller is applied, the agreement is still satisfactory, as Fig. 26 shows, although in each case the roller produces some depression, which tends to cause the experimental

FIG. 27.—*Stresses* $(p-q)$.



curve to lie above the calculated values. After a correction for this is made, both sets of values are in very good agreement. The same remark also applies to the smallest flat block, but if the area of the block is increased, there is a marked divergence, as Fig. 27 shows, and the curves have a maximum value with a turning point like those obtained when a finite length of a large plate is under compression and due to the same cause, namely, the approach to equality of p and q giving a zero value directly underneath the block, as indicated by dotted lines in the region where it was found very difficult to obtain an accurate measurement.

The inherent difficulty, which these experiments show, of determining the true strength of a material under a tension load, when it is necessary to make an indentation or scratch, however minute it may be, has resulted in attempts to avoid this source of error altogether, and it is of interest in this connexion to note that Prof. Dalby, who has devised an autographic testing-machine of great perfection, has found it necessary to abandon the ordinary methods of attaching an extensometer. In his arrangement the specimen is turned from a solid bar with collars spaced a convenient distance apart, and the extension between these latter is measured by suitable mechanism bearing lightly against the collars.

At Prof. Dalby's suggestion the Authors have examined the effects produced by the sudden enlargement of the cross section of such a test-piece.

The exact determination of the effect of a cylindrical collar is a difficult problem, although possibly not an insuperable one, but the case of a plane section of such a test-bar is relatively simple and possibly not very different from that of a specimen in the round. It has, in fact, been shown,* in another analogous case, that a change of section causes a somewhat more widely distributed local stress for round specimens than for a flat strip of the same contour. The type of stress distribution is obviously not quite the same, but the indications afforded by the problem in plane stress are valuable as a guide to what happens in the cylindrical specimen.

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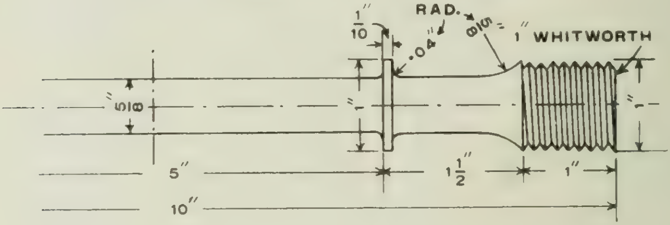
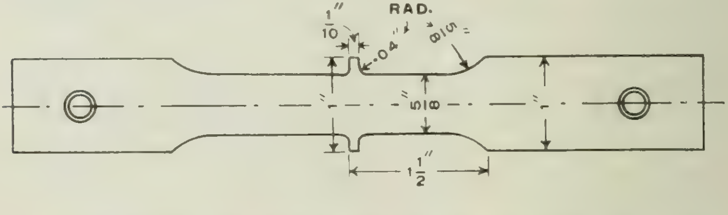
* *Loc. cit.*, ante p. 42.

The standard form used by Prof. Dalby is shown in the accompanying Fig. 28, and consists of a $\frac{5}{8}$-inch round bar provided with collars 1 inch in diameter, $\frac{1}{10}$ inch thick, and 5 inches apart, and having enlarged and screwed ends for applying load in the testing-machine at a sufficient distance away to ensure no uneven distribution of stress from these screwed ends.

FIG. 28.—*Standard Form of Dalby Test-piece.*



Dimensions of Plane Model of Nitro-Cellulose. Thickness 0·121 *inch.*



The merging of the collars into the bar is effected by fillets of 0·04-inch radius, and of the outer enlarged ends by curves of $\frac{5}{8}$-inch radius. The measurement of the distribution of stress in the screwed ends is a difficult matter and outside the scope of this investigation. It is not considered here. A slight increase of stress is known to occur near the join of the straight contour with the curves of large radius, but, as these latter effects have been measured and described elsewhere,* it is not necessary to refer to them further. The full sized model test-piece, which formed the subject of the experiments described below, was shaped in the manner shown in the lower part of Fig. 28, in which the exact contour is preserved up to the enlarged ends, and the load is applied through pins sufficiently distant from the discontinuities to ensure uniform stress in the enlarged ends before change of section takes place.

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* Proceedings, Inst. C.E. Vol. ccviii, Part II, 1918-19.

When this bar is subjected to a moderate load and viewed in the polariscope, the colour effects appear to indicate, Fig. 29, Plate 17, that in the neighbourhood of the flanges and at the rounded contour there is a local increase of stress, but the general effect of the enlargement appears to decrease the stress intensity along the lines of a truncated quadrilateral, while across the central section there are some indications of stress variation, as the photograph shows. The outermost parts of the flanges are under no stress, but their inner parts are subjected to a somewhat complex stress distribution, which gives rise to an increased tension near the join of the fillet with the parallel contours, and becomes equal to the mean value corresponding to the load at a small distance from the discontinuity. It is also fairly evident from the colour picture obtained in the polariscope that the stress is symmetrically disposed, and that the enlarged ends do not produce an unsymmetrical distribution at the flanges.

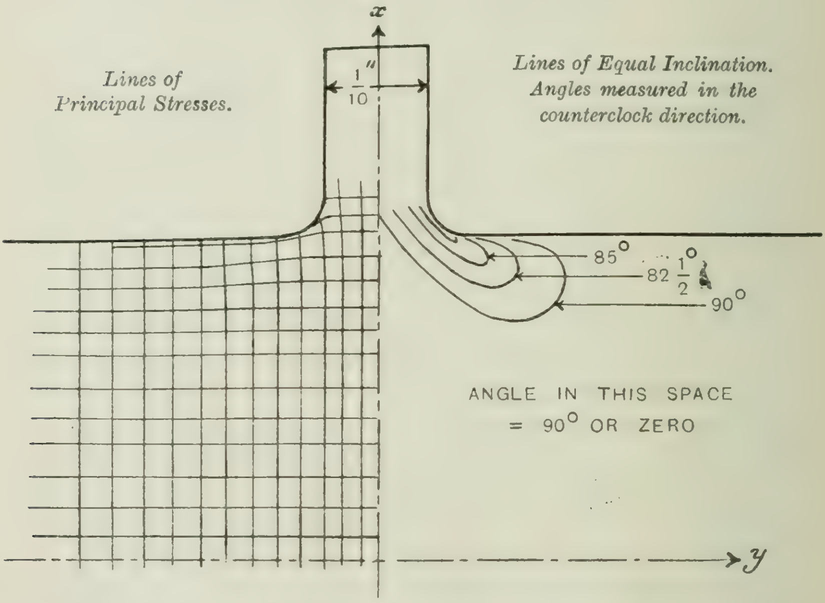
The experimental determination of the distribution in such a case can be completely solved by measuring the directions of principal stress and their magnitudes, on the assumption that the variation of stress throughout the thickness of the plate is negligible.

The former are determined from the isoclinic lines shown on the right hand of Fig. 30, from which it appears that at the enlargement caused by the flanges the lines of principal stress parallel to the axis bulge outwardly in a somewhat abrupt fashion accompanied by a divergence of the transverse orthogonal lines. The disturbing effect of this enlargement on the lines of principal stress is small, however, and, so far as this kind of evidence shows, it appears to indicate that the variation in the distribution of stress is not very great.

In order to determine the stress distribution accurately, a number of cross-sections were examined in the neighbourhood of discontinuity and the values of $(p \pm q)$ measured along them. These values are recorded in Table 12 (page 428), and a few of these are plotted in Fig. 31 to show their general character.

At the central section it is noticeable that the $(p-q)$ curve of distribution is above that of the corresponding $(p+q)$ curve for the greater part of the section, and that it rises slightly, as we proceed, away from the axis and reaches a maximum value at a distance of about 0·23 inch from the central line, as the colour effects indicated. There is then a rapid decrease to a zero value.

FIG. 30.—*Directions of Principal stresses.*



x
$\frac{1}{10}''$
Lines of Principal Stresses.
Lines of Equal Inclination. Angles measured in the counterclock direction.
85°
$82\frac{1}{2}°$
90°
ANGLE IN THIS SPACE = 90° OR ZERO
y

The measurements show, in fact, that the tensional stress across this section is fairly uniform for two-tenths of an inch on each side of the central line, with a little rise as we go outwards, and then rapidly dies away. It is accompanied by a compressional cross stress of small magnitude, which reaches a maximum value at about $x = 0·23$ inch and changes sign when $x = 0·3$ inch approximately.

This distribution is characteristic of all the sections in varying

Fig. 31.

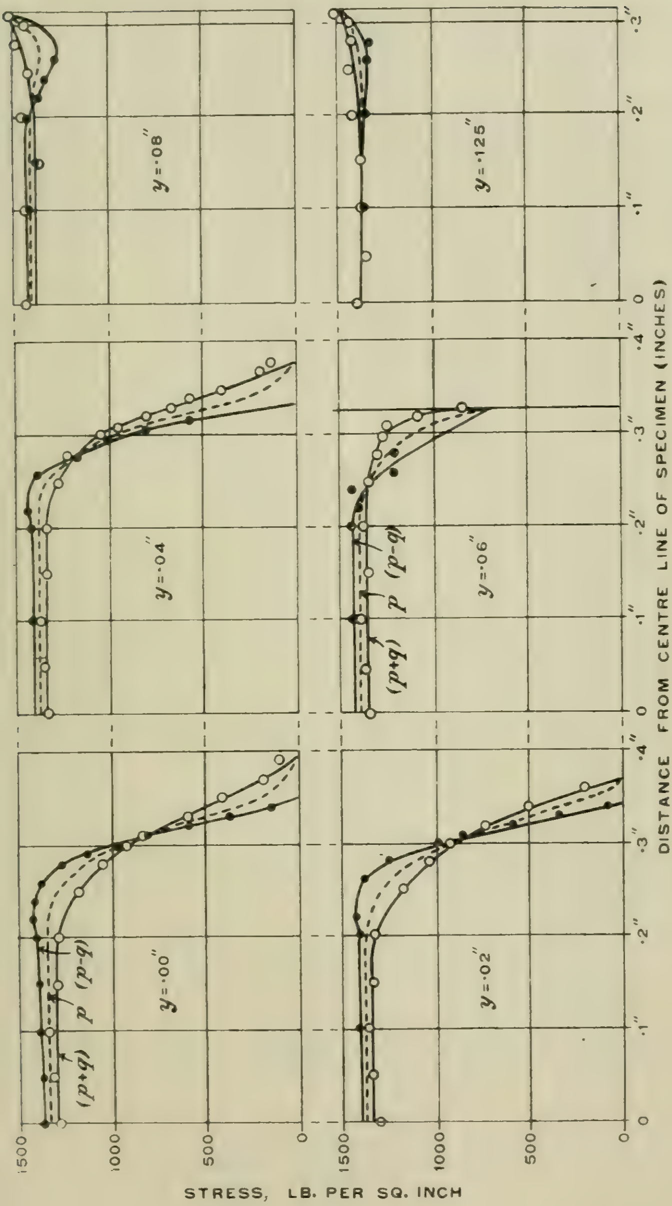

y = ·00"
y = ·02"
y = ·04"
y = ·06"
y = ·08"
y = ·125"
(p+q)
p
(p-q)
1500
1000
500
0
0
·1"
·2"
·3"
·4"
STRESS, LB. PER SQ. INCH
DISTANCE FROM CENTRE LINE OF SPECIMEN (INCHES)

TABLE 12.—*Sum of Principal Stresses* $(= p + q)$ *lb./in.*^{2}

$y =$	Inch. 0·00	Inch. 0·01	Inch. 0·02	Inch. 0·03	Inch. 0·04	Inch. 0·05	Inch. 0·06	Inch. 0·07	Inch. 0·08	Inch. 0·10	Inch. 0·125	Inch. 0·15	Inch. 0·20	Inch. 0·30
$x =$ inch. 0·00	1,302	—	1,308	—	1,320	—	1,342	—	1,438	1,302	1,374	1,302	1,302	1,373
0·05	1,328	—	1,353	—	1,354	—	1,353	—	1,380	1,302	1,335	—	—	—
0·10	1,406	—	1,368	—	1,368	—	1,380	—	1,432	1,276	1,368	1,250	1,275	1.315
0·15	1,302	—	1,342	—	1,322	—	1,335	1,400	1,353	1,302	1,368	1,302	1,263	1,368
0·20	1,302	1,250	1,328	1,432	1,335	1,380	1,360	1,471	1,452	1,263	1,413	1,343	1,380	1,413
0·25	1,185	1,172	1,178	1,308	1,262	1,302	1,348	1,367	1,419	1,308	1,432	1,302	1,387	1,302
0·28	1,055	1,035	1,042	1,250	1,224	1,275	1,290	1,387	1,483	1,353	1,419	1,380	1,368	—
0·30	925	866	911	1,042	1,042	1,210	1,250	1,380	1,438	1,335	1,438	1,445	1,510	1,530
0·31	840	800	—	917	950	1,087	1,237	1,367	1,530	—	1,510	1,484	—	—
0·32	—	—	729	768	781	925	1,068	1,191	—	—	—	—	—	—
0·33	598	592	—	664	657	814	845	—	—	—	—	—	—	—
0·34	—	—	508	527	573	638	—	—	—	—		—	—	—
0·35	401	293	—	—	390	—	—	—	—	—	—	—	—	—
0·36	—	—	202	338	—	280	—		Load on specimen = 100 lb.					
0·37	195	150	—	—	195	—	—	—	—	—	—	—	—	—
0·38	—	—	—	260	130	195	—	—	—	—	—	—	—	—
0·39	104	13	—	195	—	—	—	—	—	—	—	—	—	—

TABLE 12—*continued.*

Difference of Principal Stresses $(= p - q)$ *lb./in.*^{2}

$y =$	Inch. 0·00	Inch. 0·01	Inch. 0·02	Inch. 0·03	Inch. 0·04	Inch. 0·05	Inch. 0·06	Inch. 0·07	Inch. 0·08	Inch. 0·10	Inch. 0·125	Inch. 0·15
$x =$ inch.												
0·1	1,408	1,408	1,408	1,408	1,408	1,408	1,422	1,422	1,422	1,422	—	—
0·2	1,408	1,408	1,408	1,408	1,408	1,408	1,422	1,422	1,422	1,422	1,340	1,340
0·22	1,440	1,440	1,440	1,440	1,440	1,440	1,390	1,390	1,357	1,323	—	—
0·24	—	—	—	—	—	—	1,423	1,423	1,340	1,241	—	—
0·26	1,387	1,387	1,387	1,387	1,387	1,387	1,191	1,159	1,273	1,223	1,340	1,340
0·28	1,255	1,255	1,255	1,255	1,155	1,155	1,191	1,159	—	—	1,323	1,323
0·30	978	978	978	978	978	882	—	—	—	—	—	—
0·31	860	860	860	860	819	819	—	—	—	—	—	—
0·32	580	580	580	580	580	—	—	—	—	—	—	—
0·33	368	335	335	311	—	—	—	—	—	—	—	—
0·34	154	104	77	5	—	—	—	—	—	—	—	—
0·35	5	5	5	—	—	—	—	—	—	—	—	—

Load Calculated.

$y =$	Inch. 0·00	Inch. 0·01	Inch. 0·02	Inch. 0·03	Inch. 0·04	Inch. 0·05	Inch. 0·06	Inch. 0·07	Inch. 0·08	Inch. 0·10	Inch. 0·125	Inch. 0·15	mean.
w	104·7	102·7	104·2	104·2	103·8	105·9	105·0	106·0	103·6	100·2	102·8	99·3	103·53
Per cent difference.	4·7	2·7	4·2	4·2	3·8	5·9	5·0	6·0	3·6	0·2	2·8	−0·7	3·53

degree up to $Y = 0 \cdot 05$ inch, where the main discontinuity ceases, and only the rounded corners remain to increase the breadth of the section. We find the $(p \pm q)$ lines still cross, but, instead of terminating at zero, they reach a maximum at the curved contour.

It is interesting to note in passing that these measurements show the same kind of variation which occurs when the enlarged portion is very much longer, and that some increase of stress appears to be inevitable within the elastic limits of the material whenever there is a symmetrical enlargement connected to the main tension member by any form of curve.

An idea of the general accuracy of these measurements may be obtained by integrating the normal stress p_n across each section and comparing the value so obtained with the actual load. It will, however, be noticed that q is small and that it changes sign, so that if it is neglected altogether the error is hardly appreciable. The other principal stress p is, moreover, nearly normal to the cross section everywhere, so that if t be the thickness, we have $W = t \int p_n \cdot dx = t \cdot \int p \cdot dx$ very nearly, and we may take this latter value without appreciable loss of accuracy. This approximate check on the general accuracy of the measurement is, under these circumstances, likely to account for slightly more than the load of 100 lb., as in fact actually turns out to be the case, Table 12, except one section where the error is slightly in defect.

Except in two instances the error does not amount to more than 5 per cent and the average error is $+2 \cdot 53$ per cent, which would probably be reduced somwehat if q were taken into account, and the inclinations of both principal stress to the cross sections considered.

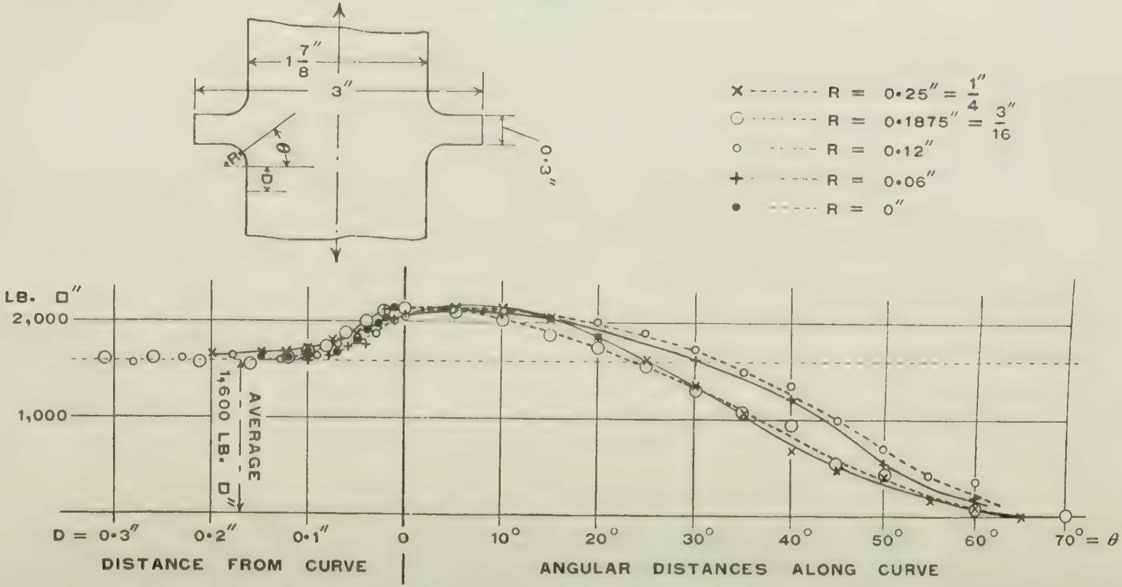
It is an interesting feature of this form of test-piece that a change in the radius of the fillet does not appear to exercise a very marked influence on the stress produced. It appears always to cause a local concentration of stress, but its effect does not change very much with curvature, whereas in re-entrant angles the maximum stress rises rapidly with the curvature.

In order to examine this with some accuracy, measurements

TABLE 13.

—	R=$\frac{1}{4}$ in.	R=$\frac{3}{16}$ in.	R=0·12 in.	R=0·06 in.	R=0 in.
Degrees.					
70	—	0	0	9	—
60	137	65	370	201	—
50	405	438	720	560	—
40	679	952	1360	1258	—
$\theta=30$	1398	1314	1764	1640	—
20	1870	1773	2004	1848	—
15	2015	1893	2056	—	—
10	2140	2015	2090	2100	—
5	2150	2100	2090	—	—
0=0	2060	2145	2035	2160	—
Inch.					
0·02	2020	2100	1960	2120	2174 2060
0·04	1940	2020	1870	1780	1906
0·06	1860	1900	1770	1740	1780
0·08 =D	1800	1760	1700	1658	1690
0·10	1760	1730	1620	1620	1650
0·15	1710	1600	1600	—	1620
0·20	1700	1600	1630	—	—
0·25	—	1610	1600	—	—
0·30	1668	1620	1600	—	—

Fig. 32.—*Peripheral stresses at Flange of Dalby Test-bar. Load 300 lb. Width 3 inch total, $1\frac{7}{8}$ inch net. Assumed thickness 0·10 inch.*



were made along the boundary of an enlarged member, in which all the conditions were kept constant, except the radius of the fillet. At such a boundary the minor principal stress vanishes and either optical or mechanical measurements suffice, but the former are preferable owing to the ease with which they can be made at the boundary. Some of these are shown in the accompanying Table 13 and are plotted in Fig. 32, for a member three times full size under a load of 300 lb., which latter load corresponds to a mean stress of 1,600 lb. per square inch. In every case a maximum stress of more than 2,090 lb. per square inch is observed, but it is noteworthy that the extreme cases give very small differences, for with a radius of $\frac{1}{4}$ inch the stress rises to 2,150 lb. per square inch, and for the smallest radius that could be fashioned the corresponding stress is only very slightly increased. The experiments, in fact, appear to show that, although flanges cause a local increase of stress, the form of the curve, by which they merge into the main body of the member, is not very important provided it does not undercut the specimen.

On the whole, the evidence afforded by the above examination appears to us amply to justify the use of this form of test-piece for tension tests, although, as Fig. 32 shows, there is a local increase of stress at or near the join of the straight contour with the flanges. This local concentration is, however, met with in the usual standard forms under less advantageous circumstances.

In conclusion, the Authors desire to express their acknowledgments of the help they have received during the progress of this investigation from the Department of Scientific and Industrial Research, and the authorities of University College also for the great mechanical skill of Mr. F. H. Withycombe in the construction of the numerous pieces of apparatus and specimens required throughout this investigation which commenced early in 1914.

The Paper is illustrated by 28 Figs. in the letterpress, and by two Colour Plates Nos. 16–17.

Discussion in London on Friday, 18*th March* 1921.

The PRESIDENT pointed out the interest and value of the information contained in the Paper, which was the first of the kind read before the Institution. Papers of a similar nature had been published elsewhere, but clearly a great deal more still remained to be done, and he trusted that Professor Coker and his co-workers were continuing their experiments, because they could not fail to be of extreme interest to mechanical engineers. The colour prints which had been shown made one realize very vividly the distribution of the stresses, and one of them clearly showed how the strength of a structural member was weakened by *adding* material. He proposed a most cordial vote of thanks to the Authors for their valuable and interesting Paper.

Sir HENRY FOWLER, K.B.E. (Member of Council), formally seconded the motion, which was carried with acclamation.

Dr. H. S. HELE-SHAW, F.R.S. (Vice-President), said that any method of research, which enabled the engineer to investigate problems so that he could improve the design of both structures and machines, was most important, but when a method was optical, so that not only could the results be accurately measured but what was taking place during variation of stress could be actually seen, the value became enormously enhanced. In the application of the methods described in the Paper use was made of polarized light. The discovery and explanation of polarized light was probably rather more than a hundred years old. He had that day perused the wonderful and classic Paper by Sir David Brewster, who was the first to give a consistent theory of the subject; though Professor Coker had told him that Sir David had suggested the use of polarized light for investigating strains in an arch, he had not seen any reference to this in the above Paper. Professor Filon, Professor Carus Wilson—and others had also suggested applications of the method of polarized light.

There was a considerable difference between suggesting the use of a method and setting to work as Professor Coker had done, and by combining his mathematical and scientific knowledge with his engineering skill to follow up the work, and he had, after many years, given engineers a practical method of solving difficult problems. In the "Philosophical Transactions" last year a Paper had appeared without which the work under discussion could scarcely be regarded as complete. In the Paper to which he referred, the properties of transparent nitro-cellulose had been carefully examined and a large amount of detail had been given. The research showed that the results obtained by the use of varieties of this substance were not only true within the elastic limit but were also true outside that limit, which was very important because it did not require very high stresses to deform a block of celluloid or xylonite.

He believed the Paper before them was the first representing any practical attempt to deal with the obscure subject of contact pressures or the distribution stress at the point of contact. Members were familiar with the text-book treatment up to the present in use for dealing with transverse stress, as illustrated by beam and girder problems, and this was simply to ignore the contact effects at the supports and point of loading, which led often to most erroneous conclusions. For instance, a girder carrying a uniform load and supported at two points, if the distance from the ends of the latter supports was $(\sqrt{\frac{1}{2}}-\frac{1}{2})$ times the length, then the text-book result was that the maximum stress was equal at the centre of the girder and at the two supports. This might be absolutely wrong, as the stresses at the three points were in general totally different according to the actual form of the supporting surfaces. It was clear from the colour diagrams they had seen that the stresses at sharp corners might be enormous, and it might be asked why, if this was so, the girder or machine part did not *always* fracture at that point. The answer was that the stresses were local, the material was indented. Of course, if the material was very hard, it might break at the point of contact. It so happened that until the nature of the contacts had been investigated, the position of the really weakest part could not be ascertained. Engineers had been obliged up to the present to be contented with an assumption which was erroneous. They had now, however, a method by which accurate results could be arrived at in regard to contact pressures. He would like Professor Coker in his reply to say if he had combined the new contact results with calculations for transverse stress, as obviously this was necessary for the complete treatment of the subject.

There were three kinds of measurement taken by the Authors, namely, (1) the magnitude of the stress at certain points ; (2) the direction of the principle axes, and lastly (3) the isoclinic lines. These last, which gave the loci of equal inclination of stresses, were very valuable although not generally employed by engineers, and it was a matter of the greatest interest that mathematical investigations, which enabled these isoclinic lines to be predicted, had been found by measurements recorded in the Paper to be verified in a remarkable way.*

The speaker next alluded to the work in connexion with test-pieces, and expressed the view that it was a very satisfactory thing that the cause of the difficulties in the use of the extensometer could be understood by the optical method and that the evil effects of the centre punch marks on specimens in connexion with such instruments were so well explained in the Paper. The Paper gave a remarkable result with a specimen of Hadfield's manganese steel which had the breaking tensile strength of 100 tons, and, although showing great extension, had ultimately broken across the minute marks made for measuring elongation. Not the least valuable part of the Paper was the record of tensile stresses induced in the neighbourhood of the collar, which had been suggested by Professor Dalby with a view to obviating the almost universal custom of indenting the test-pieces, between which to measure such extensions, and of carrying an instrument for doing this.

He would in conclusion remark that beautiful as the coloured photographs had been, it was a great pity that the Authors of the Paper had not been able to produce on the screen the actual colour effects as the contact stresses were produced. The speaker had witnessed such experiments, only a day or so before, in the laboratories of University College; and it was only because the intense beam of light required for a large lecture hall was dangerous to the valuable Nicol prisms, that Professor Coker had not given them the same pleasure of seeing actual experiments that night. For instance, in the photographs shown, a metal pressure piece was used to make contact; whereas in the actual experiments the speaker had witnessed, a celluloid pressure piece was used, and Fig. 33 showed that, at the corners of the solid piece, curves started similar to those produced in the contact surface. This visibly brought home the evil effect of sharp corners, and that it was not only at the surface of contact but in the pressure piece itself that intense stresses were produced. He would have referred to other points of great interest which became evident by witnessing the actual formation of stress colour figures, for like his own method of stream-line colour bands, the changes taking place revealed many new facts to the observer.

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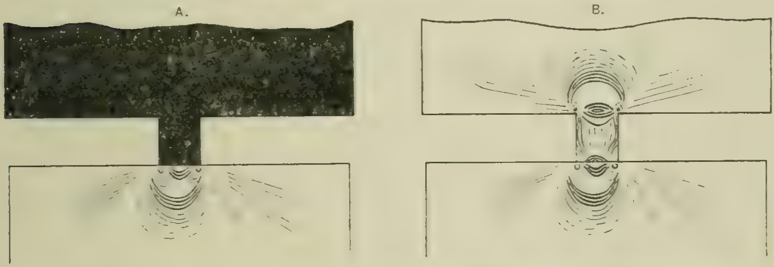
* The speaker wishes to say that he had not at that time had an opportunity of reading the Papers by Professor Filon (as he has since done), or he would have paid a tribute to his remarkable investigations on this subject

Fig. 33.

A *is a diagrammatic Fig. of the coloured photograph, Fig.* 8, *Pl.* 16.
B ,, ,, ,, ,, *which shows what is really also happening to the Pressure Piece.*

Thickness of material $\frac{1}{4}$ inch. Specimen 1 inch square.
Pressure applied over $\frac{1}{8}$ inch width. Load 55 lb. approx.



As in various times his stream-line method had been suggested, and even used with the idea of giving stress diagrams in riveted joints in the structure of ships and other cases, he took this opportunity of saying that he, the speaker, had never suggested their use. Though in some cases bearing a certain similarity to the actual lines of stress as revealed by polarized light, the stream-line method could not really be applied to this purpose, any more than the colour bands of polarized light could be applied, as the stream-line method could be, for the flow of liquid, or for electric or magnetic problems. He believed that the method that the Authors had brought before them was the only method that had ever yet been suggested for investigating the hitherto obscure and unknown problems of contact stresses.

Professor L. N. G. FILON (University College, London) said it was not often that a mere mathematician like himself had the work of his callow youth disinterred out of the dust of oblivion by a real live engineer, and moreover had it tested, and he was very proud to say, verified, with the great conscientiousness that characterized all the Author's work, and which had been exemplified in the remarkable Paper that had been read. So far as the verification of the theoretical results was concerned, he thought the agreement was very striking. He desired to refer to some of the results of pages 420–1, to which Professor Coker had alluded very briefly that evening, namely, the comparison between the calculated and the observed values of the stresses in a beam immediately underneath a point of concentrated load. There were some discrepancies between theory and experiment in that instance, but what struck him most particularly was the curious divergence between the law of stress according to the particular form in which the load was applied. If a 60 deg. knife-edge were used, for example, a series of stresses all smaller than the calculated value were obtained, and they got proportionately smaller as one moved away from the load. Again, if a flat punch were used discrepancies were obtained, but if the punch had a width of about $\frac{1}{8}$ inch, apparently the agreement for moderate depths was very much better. Again, if a round pin were used, the discrepancies varied considerably with the diameter of the pin. For a diameter of $\frac{1}{8}$ inch there was again a most remarkable agreement, which in that instance continued all the way down, with the results of theory. He had been somewhat exercised in his mind about those divergencies. Of course, it was possible to see how, even according to theory, the shape of the punch might affect the law of stress; but he would not have expected changes of the order shown, especially at a distance from the point of application of the load.

In that connexion he would like to call attention to certain possibilities that might have to be considered in regard to celluloid. It so happened that he had recently been carrying out some experiments on the physics of stress in celluloid, both in regard to its optical effect and to the extension of celluloid under tension. It appeared that that material, even under loads which were apparently well within the elastic limit, showed a considerable creep after several hours. It went on creeping for days and even for weeks. For a load corresponding to the order of extinction in some of the slides shown that evening as much as 17 per cent of optical creep could be obtained inside one hour, that is, the optical retardation, by means of which the stress difference $p-q$ was measured, might vary as much as 17 per cent of the whole. Further, the photo-elastic properties of the material appeared to be very profoundly influenced by previous treatment, especially if the loads had been considerable. If the specimen, after being unloaded, was allowed to rest for a couple of hours and then loaded again, it was found that the stress optical coefficient, as it was called, had varied to a certain extent, and that the optical effect had proportionately increased. For a moderately heavy load that change might amount to something like 4 or 5 per cent of the whole for an interval of measurement of about 90 minutes, that is, if one took $1\frac{1}{2}$ hour over the measurement, the effect might come in between two successive sets; but for smaller loads it was much less. He would like to ask the Authors whether they thought that might possibly account for some of the minor discrepancies.

He was very pleased that the Authors had taken up the method of the isoclinic lines. Much of Professor Coker's past work had been done by using the colour bands called isochromatic lines, which corresponded to relative retardations of 1, 2, 3 or 4 wave-lengths, and they required very considerable loads for their production, whereas the isoclinic lines, that is, the loci of the points where the axes of principal stress had all the same orientation—those loci which were shown by black brushes or bands in the field—could be produced with extremely small loads, and therefore the element of uncertainty to which he had just been referring was absent. He held in his hand a copy of the *Philosophical Magazine* for 1912, in which some of those isoclinic lines were shown on some plates; and he remembered using the method about twenty years ago at Cambridge, in order to investigate that very problem of the stress in a rectangular bar of glass under a point of concentrated load.

With regard to the combination of the ordinary flexure stress with the local stress, which had been referred to by Dr. Hele-Shaw, he might say incidentally that glass was a very troublesome material with which to investigate the stresses in complicated engineering structures, and he thought one of the very great merits of Professor Coker's process, and one which really amounted to a great discovery, was the use of celluloid. He did not know of the photo-elastic properties of celluloid at the time, so he used glass. A rectangular bar of glass rested on knife-edges; there was a central load and there were wooden projections which enabled him to apply a reverse bending moment in the part of the bar between the supporting knife-edges. By varying the reverse bending moment, he could vary the ordinary flexure stresses and adjust them so as to cancel local stresses at a given point, thus obtaining a null result. The method gave results which confirmed the theory to a certain extent (there were certain discrepancies), but there was no doubt about it that, in view of the methods that the Authors were now bringing to bear on such problems, his own early experimental attempts were very inferior, and probably the discrepancies between theory and observation that they seemed to show might have been due to that cause. He had been very much struck by the examples and slides shown by Professor Coker, the excellence of which he felt sure must have been noticed by everyone present. The reproduction of the actual colours was so accurate that, when the early slides were being shown, he really thought that the actual specimens under stress were being introduced into the lantern.

Mr. C. E. STROMEYER, C.B.E., said the Authors had done excellent spade work, which would throw a great amount of light on many problems with which engineers had to deal. The work was so complete that he could not offer any criticisms ; and he would, therefore, confine himself to a few suggestions. The first was with regard to Fig. 4 (page 371). The stress diagrams reminded him very much of the pressures which occurred in a bearing, and it seemed to him that this experiment could be brought nearer to mathematical conditions if, instead of a rectangular sheet resting on a flat surface, a celluloid half-disk were cemented into a nearly rigid bearing, and if instead of a point contact, the top of the disk were hollowed out as far, perhaps, as the first stress ring, and a cylindrical metal plug cemented into the hollow. It would then be possible to a certain extent to comply with the mathematical boundary conditions both for the centre and for the outside.

He thought that in spite of what had been said against streamlines, they might be made very useful if, instead of resolving movements, as was done by Rankine, stresses were resolved. That, of course, implied that double the angles should be used instead of single ones. A far more important suggestion than either the above was that very considerable light would be thrown on many engineering problems if the Authors would deal with the problem of stresses in a curved beam, of which that of a thick walled cylinder was a unique case.

Professor L. LUIGGI, D.Sc., said he desired on behalf of Italian engineers to express gratitude to the Authors for the work they had done. In some countries, not England or Italy, engineers were being taught in these latter years almost entirely from a mathematical science point of view, it being forgotten that engineering was also, and principally, a physical science. He was glad that the Authors, by taking up the physical part of research, had brought engineering again into its proper channel. An engineer ought to do by experiment everything that he possibly could, in order to ascertain the structure of materials and the best way of using them, and he ought not to use the reasoning of his brain until all those experiments had been exhausted. If, on the other hand, an attempt were made to reason before all the experiments had been exhausted, assumptions might be made that were considerably away from the truth, and this had happened many times. For that reason the Authors' experiments, as well as those by Professor Mesnager, in Paris, had been followed with the greatest interest by Italian engineers. Not only engineers, but also men of scientific attainments, such as Professor Corbino and others, had followed the experiments with the greatest interest.

The Authors showed in a practical way how engineering ought to be studied and taught, namely, that a proper proportion of physical research work should be undertaken first, to be followed by not an excessive amount of mathematical reasoning. Mathematics had to be used when nothing else was available. High mathematics were like a microscope, which was to be used to see things which could not be seen with the naked eye ; but if a thing could be seen with the naked eye, this should always be used, and Professor Coker's experiments tended to that aim. That was also what Leonardo da Vinci taught. With reference to water, he said : " When you have to deal with water, first do all the experiments, then see what the facts can teach you, and leave the reasoning to the last." That remark could be applied by all students of engineering. Galileo, who was the first to experiment on the resistance of materials, also recommended students to experiment first and to reason about them afterwards. He was well aware of the fact that that was contrary to the teaching of the ancient school of the Greeks, who were great philosophers and not experimenters. The engineers of some countries, fortunately not England or Italy, were, he was afraid, going astray and following the Grecian school. He assured the members of the Institution that he felt that at the Meetings of the Institution of Mechanical Engineers he was really in an atmosphere of proper physical research.

Professor E. G. COKER, in reply, said it was extremely gratifying to his colleagues and himself that the Paper had been so favourably received, and he desired, on behalf of the Authors, including Mr. Ahmed, who was unable to be present, to thank the members for the interest they had shown. Dr. Hele-Shaw covered such a wide field in his remarks that he was afraid time would not allow him to make an adequate reply, but in the few minutes which had been placed at his disposal he would attempt to reply to one of the very interesting matters which had been raised. The point in connexion with the beam, where both bending moment and contact pressure were obtained, was a most interesting one. He believed that Professor Filon had attacked this problem mathematically, and the speaker had himself examined it experimentally (*Engineering*, 19th January 1921), although somewhat superficially. He could not say very much about it, therefore, as so little work had been accomplished on this complicated problem.

He had been extremely interested in Professor Filon's remarks. As many of the Members knew, Professor Filon had devoted many years to the study of the mathematical side of elasticity and to investigations of the physical laws of photo-elasticity. In the discussion he had drawn attention to the results which were obtained with regard to the contact pressures shown by Fig. 24 (page 420). The Authors also regarded these discrepancies between experiment and theory with some concern, especially as this seemed at first sight an ideal case for comparison purposes. There was, however, much better agreement for the cases of flat plates of small area and small cylindrical rollers applied at the sides than for the case of the knife-edge. The explanation of this was possibly due to the fact that a knife-edge in these experiments did not behave as an isolated load, as assumed in the calculations described with reference to Figs. 22 and 23. It pressed into the material like a wedge as the colour photograph, Fig. 25, Plate 17, showed, and under these circumstances the transverse stress q was not that of the formulæ anywhere, nor, for that matter, was the stress p. He was very glad to hear what so high an authority as Professor Filon had said about the physics of celluloid.

He would like to say as regards this Paper that the Authors were well aware that celluloid was not a perfect material (no material was perfect) ; but although not an ideal material to work with from the point of view of its elastic properties, it happened to be exceedingly convenient to use. Glass could not be freely used for engineering purposes, because it was impossible to make the models required. He desired to point out that nitro-cellulose, like most other materials, varied greatly in quality, and at the commencement of this work especial care was taken to select the most perfect pieces as regards optical quality from pre-war stocks at the factory. As the war progressed, makers found it more and more difficult to obtain their proper basic materials, and even now that difficulty had not been entirely overcome, and the optical quality of post-war material was only slowly approaching that of pre-war material. This made little difference to its commercial use, but as the material on which Professor Filon was working was all of post-war manufacture, he would, as time went on, probably find that the imperfections of this later material, to which he called attention, were less and less apparent. The speaker also desired to say that when he was making observations, all the colour effects which had been seen that evening, were compared with those of another standard member, which was stressed to the same extent. The model and the calibration member were stressed at the same time and continued to be so stressed from the nature of the experimental method adopted, so that if the discrepancy due to the effect of continued loading was present, it was going on at the same time in both bodies, and was therefore practically eliminated by his arrangements. He was perfectly familiar with the fact that creep could occur, and it must be recognized by those who desired to undertake such work. He thought the remarks he had made helped to show how the difficulty could be met.

With reference to Professor Filon's remarks on the subject of isoclinic lines, he had always used them to the fullest extent he could, as even his earliest Papers showed, but Professor Filon and he approached the subject from rather different angles, the one as a mathematician and physicist and the other as an engineer. The mathematician could choose his own problem, and he usually selected one which was mathematically solvable and for which therefore isoclinic lines could be calculated and tested by experiment, but the engineer could not so choose, because he was obliged to deal with existing problems which were generally beyond any form of mathematical reasoning available. The engineer investigator was, in fact, bound to take the machine or structure as it existed or had to be built, and try and find out what the stresses were. He was very glad to note that the maker of the colour photographs was present, to whom Professor Filon had paid such a high tribute, and he was sure that Mr. Norris appreciated it.

With regard to Mr. Stromeyer's remarks, he was afraid the suggested cure for preventing indentation was not very useful. As the Paper showed, there was some difficulty in measuring the distribution of pressure between two flat surfaces pressed together, and if two semi-circular surfaces of discontinuity were introduced, it would become necessary to make an elaborate investigation of the distributions across the surfaces of separation, while the problem became less interesting from a practical point of view owing to the cuts in the material.

He could not agree with the remarks Mr. Stromeyer had made with regard to the use of stream-lines, as that method was not applicable, except in very special cases. The fundamental equation of plane stress was $\nabla^4 \cdot \chi = o$ and if that equation could be solved generally, every kind of stress distribution in a plane was *ipso facto* solved. But this stage had not yet been reached. The fundamental equation in plane hydrodynamics was, however, $\nabla^2 \cdot \chi = o$, and there were apparently some cases in which these two equations became identical. These coincidences had proved very misleading, and many writers, both here and abroad, had assumed quite inaccurately that lines of stress and steam-lines were identical. It was impossible for stream-lines to give the information required for stress problems, because they were essentially different, as the fundamental differential equations showed, one being of a higher order than the other.

With regard to Mr. Stromeyer's further remarks, he desired to reiterate what he said in his opening remarks before reading the Paper, that an attempt was made here to deal with flat bodies pressed against flat bodies only. He might, however, say that the Authors had done a great deal of work on bodies of circular form, but he could not discuss this on the present occasion, beyond mentioning that several cases had been worked out, including some problems on rings and rollers.

The Authors were greatly obliged to Professor Luiggi for his interesting remarks and especially for the point of view he took as to the way engineering investigation ought to be conducted They appreciated these remarks very much, especially from so high an authority on engineering as the President of The Italian Institution of Civil Engineers.

Discussion in Manchester, on Thursday, 21st April 1921.

The CHAIRMAN (Mr. CHARLES DAY, *Member of Council*) said he wished on behalf of the members to thank the Author for his most valuable Paper and for giving them a most interesting Lecture. To see the actual effects of stress illustrated by colour photography appealed to him, as opening up an entirely new line of investigation of stress problems, and he felt that Professor Coker had put before them ideas which, before many years had passed, would yield very important results.

Professor A. H. GIBSON, D.Sc., said he would like to express his deep appreciation not only of the Paper but also of the long series of research upon this subject which Professor Coker had carried out during the last thirteen or fourteen years. They all knew that, within certain well-defined bounds and under certain well-defined conditions, many problems of stress could be worked out mathematically, sufficiently closely, at all events, for engineering purposes. A point was reached, however, at which the stresses became so complex—especially if the structure or member was itself of complex form, or if the application of the stress was anything but simple—at which the distribution of stress passed the bounds of mathematical analysis. Under those conditions, the method outlined and developed by Professor Coker was practically the only one which gave any means of getting even approximate values. Errors of a few per cent might occur—it was difficult to get really accurate determinations of stress from this colour method, but when it was compared with the errors which might creep into a mathematical calculation, it was very evident that, even from that point of view, this method had very much to recommend it.

They had seen from the Paper and from the photographs shown that the application of a lateral load to a tension specimen increased the stress very considerably. Professor Coker had instanced the application of an extensometer by means of two contact points to a specimen. He had also instanced another case—rather a peculiar one—in which the addition of a small collar to a specimen increasing its diameter actually caused the stress in the specimen to increase by something like 30 per cent. They all knew that if the specimen were tested to destruction in a testing-machine, it would not break at that place. He had brought to the Meeting two specimens which bore upon that point rather well. One was a specimen of round iron and the other was of rectangular section. Both were tested in the rough in a testing-machine between ordinary tooth-grips. They would notice the depressions which the grips themselves had made in those specimens. That occurred in every case with such a specimen under test, but in spite of it, out of 100 specimens tested not more than two or three broke in the grips; they always broke between the grips where the stress was more or less uniform. It would also be observed that, in the round specimen for rough purposes of measurement, centre punch-marks were placed at intervals of an inch along its length. That day he had examined about 20 specimens, all of which had been marked in the same place and none of them had broken at a centre punch-mark. The point he wanted to make was that with a ductile material—such as most engineering materials were—tested under static load, these secondary stresses did not seem seriously to affect the ultimate strength of the structure. But it should be emphasized that it was not at all the case under different conditions. Take a material—say one of the specimens of Professor Coker—and subject it to a very rapidly applied load, especially a rapidly alternating load. Then the results became very different, more especially if the material was one of the modern high-tensile steels with a very high elasticity.

Some time ago a large number of tests were made at the Manchester University on specimens of the same general type as those shown by Professor Coker. They were short, about 1½ in. between the shoulders. The shoulders were well-rounded and the diameter of the specimens was about a quarter of an inch. Loads were rapidly applied, about 2,000 alternations a minute. In a large number of cases rupture took place, not in the parallel portion of the specimen, but at the shoulder where Professor Coker's diagrams had shown the maximum stress would occur. He had often wondered why they should break there, and he thought possibly there had been a small flaw in the material, but the true reason was made clear by Professor Coker's research. He thought it was in such cases —rapidly applied loads on materials not very ductile, and of very high tensile properties—that the results shown in the Paper could be more particularly applied.

Professor G. GERALD STONEY, F.R.S., said that Professor Coker's Paper was of the greatest importance to engineers, and explained many fractures that otherwise would be difficult to understand. Professor Coker had shown that in a riveted member, such as in a bridge, the stress at the edge of a rivet-hole was about three times the mean stress due to secondary stresses. Fortunately, by having a ductile material, which was absolutely necessary, such stresses would relieve themselves automatically by the material stretching. In the case of alternating stressses, however, as Professor Gibson had pointed out, such relief did not take place and they got fracture. Similar stresses occurred where there was a change of diameter in a shaft, and he believed engineers were not sufficiently alive to the importance of having a very large radius when there was a change in section. He was not sufficiently familiar with the work to know whether the investigation could be carried out as to what radius was advisable, but if it were, it would be of very great value to engineers.

Another thing which the Paper showed was the importance of having a smooth surface with no surface irregularities. It was well known that tensile test-pieces in many materials were liable to break at the punch-marks put on them to record the elongation. That was especially the case with some of the high tensile manganese bronzes, and other high tensile bronzes. In ordinary high-grade steel the state of the surface made a very considerable difference in the tensile test results. In a large number of test-pieces taken off the same forging of a high tensile steel, it was found that it made a very marked difference whether the test-piece was ground or only turned with the usual finish. Grinding was found to increase the tensile strength by about 1 per cent and the elongation by no less than 7 per cent, while at the same time the variation in the results obtained from individual test-pieces was largely reduced. In the case of the turned test-pieces, there was a variation in tensile strength between the highest and the lowest of the batch—there were twelve or fourteen in the batch—of 4·3 per cent, while in the case of those that were ground it was reduced to 3·7 per cent at the extreme limits. In the case of the elongation the effect was even more marked, as the maximum difference for the turned test-pieces was 14 per cent and for the ground ones only 8 per cent. It was not, perhaps, so much the case with mild steel, but certainly with high carbon steels, nickel chrome and so forth, it was most important to grind the test-pieces. A good finish was most important in all material which was exposed to high stress, especially alternating stress, and there was a real reason for polishing and finishing well such parts as the connecting-rods of aeroplane engines. By that they probably increased the strength very much. He had seen an engine made by Sulzer in which every part was most beautifully finished. It seemed a waste of money, but Professor Coker's results seemed to show it was a real benefit. Of course, in ordinary cases it was very doubtful whether high finish would pay.

He would like to draw attention to the habit of inspectors of making inspection marks all over an article. As a rule they chose for their inspection marks the place which was exposed to highest stress, and if it was analysed he thought it would be found that a perceptible number of breakdowns of aeroplane engines in the war were due to such stamping. In going over an aeroplane, he was astounded at the way beautifully finished pieces of work were marred by inspection marks stamped here and there all over. If Professor Coker's work induced inspectors to pay more attention to where they put their inspection marks, it would be of very great value.

It would be of great interest if endurance tests could be made on similar specimens taken from the same bar and carefully heat-treated in the same way—some turned with an ordinary finish, some rough turned, and others polished, in order to see whether under alternating stress there would not be considerably more endurance with the really well finished article. Mr. Stromeyer had done a great deal of that kind of work and perhaps he had investigated this point.

Mr. C. E. STROMEYER, O.B.E., said he had spoken on the Paper in London, and he did not wish to repeat his remarks, but he would reply to the inquiry which had been made about the subject of polishing. That subject had been very carefully investigated by Messrs. Eden, Cunningham, and Rose.* They made a very large number of tests and polished some specimens. As far as he could remember, the result was that the polished specimens gave better results than the others. Some years ago he analysed those experiments carefully and was struck with the great discrepancies which existed between specimens of the same bar. Fortunately when he made inquiry at The Institution of Mechanical Engineers, they were able to give him the numbers stamped on the specimens, and these numbers were said to be stamped in the order in which they were cut off the rolled bar. On plotting the results on the lengths of the bars, he found that there were "peaks" in the test results occurring about every four feet, and he suggested at the time that the explanation of those irregularities was that the rolls in which the bars were rolled were not quite regular, and the rolled bars were therefore thicker at some points than at others. When they were finally drawn through the dies, the thicker parts would receive a heavier pressure than the other parts and would therefore be of different quality. This showed that a very slight difference in mechanical treatments might affect the strengths of the materials very much.

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* Proceedings, I.Mech.E., 1911, page 873.

The question of the radius for a shaft had been raised. When at Lloyds' he condemned about 60 crank-shafts in marine engines, and, having kept records including indicator diagrams and other details, he was able, some years ago, to present an analysis to the Institution of Naval Architects, in which the conclusion was drawn that the strength of a crank-shaft under the working conditions in a marine engine was not proportional to the cube of the diameter, but to the cube of the diameter multiplied by the square root of the radius of the fillet. This result confirmed the general feeling amongst engineers, that the radius of the fillet ought always to be as large as possible.

The present subject of stress distribution was exceedingly interesting, and all engineers must be grateful to Professor Coker for having started and continued his experiments. If, at some future time, local stresses in structures could be estimated, it would be possible to reduce the factor of safety. He was the first to have coined the expression that the factor of safety was a measure of our ignorance, ignorance as regards the quality of the material and especially ignorance as regarded local stresses. To a large extent, engineers still designed parts of machinery by rather rough though very simple rules. Not knowing the exact behaviour of materials nor the exact local stresses, they had to allow a factor of safety which was at present perhaps not large enough for complicated parts and too large for simple parts.

In the early days of manganese steel, he was at one of the German steel works where they had adopted Hadfield's process of making manganese steel. They showed him large piles of ingots which they had made in a small Siemens furnace. It was, he thought, during the Boer War, and the question of broken bayonets had been very much discussed. It occurred to him at the time that it would be a very good thing to make bayonets of manganese steel. They forged a sword of that steel and it was struck several times on an anvil. It stood the test very well ; the edge of course, was blunted, but otherwise there was no harm done. But one of the managers began to fence with it, and accidentally struck something, when the steel broke off in his hand. It showed that some materials were very unreliable. He believed some of the discrepancies mentioned in the Discussion were due to local strains which existed in the specimens themselves. Of course, mild steel was less likely than harder steels to have these local strains.

Mr. E. G. HERBERT said that one of the photographs showing stresses in a tensile specimen with enlarged ends reminded him of a fact that had often struck him in making autographic tests, namely, that fracture usually occurred in the region between the gauge-points and only rarely at the ends outside the gauge-points. According to what was generally believed as to the effect of a change of section, one would expect fracture to take place usually near the enlarged ends, but this was quite contrary to his experience. As to plain specimens without enlarged ends, he was in complete agreement with a previous speaker (Professor Stoney). Although such specimens were mutilated and sensibly reduced in section by the sharp teeth of the grips, fracture rarely took place in the mutilated portion which was subjected to compound stresses, but usually in the uninjured central portion where the stresses were uniform.

One of the photographs, showed a tongue of lightly stressed material extending from the enlarged end a long way down the centre of the central or reduced portion of the specimen, and one might assume that a similar tongue of lightly stressed material would appear in a plain specimen, extending from the portion held in the grips. Unstressed material would not ordinarily be regarded as a source of strength. If parts of a specimen were not taking a due share of the load, other parts must be taking an undue share, Nevertheless, the phenomenon exhibited in the photograph, in conjunction with the comparative immunity from fracture which was observed in the regions where it occurred, seemed to call for further investigation, for which Professor Coker's method would be admirably adapted. He would merely throw out the suggestion that the rather sharp surface of demarcation between the stressed and unstressed regions (a roughly conical surface in cylindrical specimens) might be the natural surface of cleavage when rupture took place, thereby giving rise to the familiar conical type of fracture, and that this conical area being greater than the cross-sectional area of the specimen, the liability to fracture would be less. He invited Professor Coker to confer a benefit on the engineering profession by proving that a change of section was a source of strength.

Dr. GILBERT COOK said he was not clear about one point in regard to the test of the manganese steel bar which broke at the point of attachment of the extensometer. Professor Coker had described the stress distribution produced by the pressure of the extensometer pivots, and he (Dr. Cook) understood Professor Coker to attribute the fracture at that point to the disturbance thus caused. Presumably the extensometer was removed before fracture occurred, and it would therefore be only the residual stresses due to local overstrain at the points of attachment that could modify the stress distribution. He would be glad to know whether the Author had measured such residual stresses.

He was very much interested to hear that Professor Coker had applied this method of stress determination to cases in which the surfaces were not plane. He referred to this because he was at present interested in a problem which, although it had no direct connexion with contact stresses, the description of Professor Dalby's test-piece afforded some excuse for doing so. If this bar, instead of being solid, were hollow, that is, if it represented a pipe with comparatively thin walls, and the collar represented a flange, or one of a series of rings which were now occassionally used to strengthen high-pressure hydraulic pipe-lines—what was the effect of that ring or flange when internal pressure was applied? Mathematical analysis appeared to show that, so far from strengthening the pipe, the rings might in certain cases actually weaken it; that is to say, the stresses in the pipe might be increased instead of reduced. He would, however, hesitate to accept such a conclusion in the absence of experimental confirmation. This was a case in which a flat plate, however adequate for the determination of the stresses in Professor Dalby's test-piece, could not in any sense represent the conditions. He would be glad to know whether Professor Coker had investigated the stresses in tubes and pipes by the optical method. If it could be developed to do so, considerable light would be thrown not only on that problem, but on the analogous and much more important problem of the stresses in a boiler-shell near the end-plates.

Mr. HARRY RICHARDSON said he could understand the various colours of the spectroscope at the point of contact of the teeth due to the pressure exerted, but would like an explanation of the colours near the root of one of the teeth of the gear-wheels.

Mr. HERBERT CARRINGTON remarked that he would like to add a few words further to what had been said about the tensile test illustrated on page 409. The load extension curve continued to rise right up to the point of fracture, whereas for ordinary mild steel and wrought iron the curves fell near the end, the fall corresponding with local drawing out of the bar in the vicinity of the fracture. It would appear that the material tested by Professor Coker was somewhat exceptional, and that it fractured like a brittle material although the elongation was considerable.

From a consideration of the dimensions of the fractured bar, there was a slight drawing out, but an examination of the curve strongly suggested that this was not purely local, but extended some distance on either side of the fracture. He would like to ask Professor Coker whether he thought that centre dots and scratches tended to determine the place of fracture only in the case of brittle material or material which broke like a brittle material, that is, with little or no local drawing out, and that the tendency was negligible in cases where the local drawing out was considerable, as, for instance, for ordinary mild steel.

Mr. Leonard F. Massey said that he had been much struck by the distribution of stress shown when the material was subjected to an evenly distributed load, the greatest intensity of stress in such a case being at the extreme ends of the loaded surface. His interest lay in the fact that a very similar phenomenon was already familiar to him in hot forging of steel. When striking a steel bar with a narrow pallet in a steam-hammer, lines exactly similar to those shown in the figure could, under favourable circumstances, be distinguished by an intenser redness in the material. If a cold bar were struck hard and continuously by such a pallet, the phenomenon could sometimes be seen by the bar heating to redness down the lines in question. These lines marked an inverted isosceles triangle whose base was the line of the pallet, the other two sides being the red lines in question.

It would seem therefore that the phenomena revealed by Professor Coker's experiments on solid materials had a very close parallel when dealing with a plastic material, and the speaker had been very much pleased to see something of a theoretical demonstration of that with which he had already been familiar by closely watching the process of hot forging.

Professor Coker, in reply, said that many of the matters raised in the discussion were not only interesting but also difficult to answer. He was afraid he had not made it clear during the evening that all the natural colour photographs of the material which were shown on the screen were of stress distributions within the yield-point, except where an obviously black patch occurred due to the crushing of the material locally. It was important to emphasize that in a ductile material like mild steel or nitro-cellulose the distributions changed in the plastic region and the stresses tended to equalize. In a brittle material, on the other hand, such as cast-iron, the distributions shown probably persisted up to fracture, and results were obtained which corresponded closely to those which one would expect from photo-elastic observations taken within the elastic limit.

He was very interested to hear what had been said about alternating stresses. Apparently alternating stress gave results in a ductile material corresponding to what might be expected in a brittle material under steady load. Therefore, as Professors Gibson and Stoney pointed out, they obtained fractures such as were indicated as probable by the colour photographs; although they might not be so obtained in a static test.

Professor Stoney had drawn attention to the fractures which sometimes occurred at changes of section in turbine-shafts and at the rectangular grooves turned in them. This was a very interesting matter and one of his assistants had been working on it recently, but the measurements had not advanced far enough to enable an adequate reply to be given; speaking generally, the distributions appeared to resemble corresponding cases described by the speaker in a recent Paper on stresses in tension members referred to above. Another question which had been raised by one of the speakers, Dr. Cook, with respect to the stresses in members of circular cross-section, and here again the speaker would not take up time by describing the flat cell method referred to in the above Paper in order to obtain an experimental solution.

As regards the effect of surface finish upon fracture and extension, Professor Stoney had made some interesting observations of great value, and possibly not very well known. In regard to these he would like to mention some experiments made a short time ago in the laboratory at University College upon the effects of slight roughnesses and the like. These could be easily produced and their effects observed at the edges of a nitro-cellulose specimen. If, for example, one took an ordinary flat bar and loaded it in a testing-machine, a uniform colour was obtained corresponding to the load and there would be no unusual effect at the edges if these latter were quite smooth. If, however, a slight mark was made, say, by scoring with a penknife, and the region was examined by aid of a microscopic attachment, bands of colour could be observed of a characteristic form and generally consisting of two bright rays at about 45° to the edge, and tending to persist as the load increased. With alternating stress well below the yield-point of the main body of the material, these colour effects became permanent and penetrated more and more into the material as the number of alternations increased, and finally they seemed to cause fracture of the specimen. That, he believed, was what roughness of surface tended to produce in stressed material. It initiated high local stress which enlarged the scope of its effect with increasing load and also with repetition of load. It appeared to the speaker that this subject could be investigated still further by optical means, and he would like to point out that an advantage of such a method of attack was that microscopic methods seemed unnecessary. Scratches and roughnesses of surface when magnified could be represented in the plain bar by some form of notch, and provided there were no other disturbing boundary condition or applied force near, one could take any size of notch which happened to be convenient for examination. This appeared to be a sound line of attack, and mathematical reasoning seemed to support it. So far as the speaker was aware, there were no accurate mathematical solutions of the stress distributions caused by notches, but, in the related subject of holes of circular and elliptical forms in tension members, analysis showed that the size of the hole made no difference to the distribution in its neighbourhood, provided the bounding edges of the plate were sufficiently far away, and the inference that this also held for notches under similar conditions seemed a legitimate one. Some experiments on this basis were now in progress for investigating scratches in materials, and the speaker hoped to be able to describe them at a later date.

He was very interested in Mr. Stromeyer's remarks, and especially in his formula for the strength of a shaft which brought in the radius of the fillet. The speaker did not quite understand how it was obtained, but it appeared to him to be something new and important because all the experimental work done so far seemed to show that the radius of the fillet had a very marked effect.

The point which Mr. Herbert raised could be answered by reference to the detailed measurements of stresses in tension members used in testing materials and referred to above, and as he was bound to be brief, he would content himself with indicating this source of further information.

With regard to Dr. Cook's inquiries, his earlier remarks concerning the method of enclosing solid cylindrical specimens in flat cells were intended to explain what had been done in this direction. So far as the speaker was aware nothing had been done with regard to pipes, but he saw no reason why a similar arrangement should not be devised on these lines for examining pipes in which strengthening rings were used to reinforce them in hydraulic mains, particularly those used for distributing water to turbines in hydraulic power-houses. The same remark also applied to boiler shells, and although it might be extremely difficult to construct such experimental apparatus, he did not think it was inherently impossible.

The gear-wheels which Mr. Richardson had drawn attention to were only intended to illustrate some general introductory remarks in the Paper, but it might be of interest to mention that the stresses at the boundaries of the teeth forms had been measured, except at the points of contact, while the directions of the stresses throughout were also known, but so far they had not worked out the distribution of stress in the interior of a wheel. Mr. Richardson had remarked on the high value of the stress at the roots of the teeth in contact, and this high stress was generally found, but what was still more worthy of note in large-toothed wheels with radial arms, was the large stresses at places in the rim and in the arms far away from the teeth in gear.

In the test on the "Hadfield" steel bar, referred to by Mr. Carrington, there was a slight reduction in section at the fracture. It was important to remember in this connexion that the fracture occurred at one end of the gauge length where two small indentations occurred owing to the attachment of the extensometer in the early part of the test. As the data showed, the extension was remarkably uniform throughout.

The remarks of Mr. Massey on forging seemed important and worth following up. They seemed to be very interesting cases of the behaviour of stresses in plastic material, although possibly there might be other features of interest in them. One of the advances which would have to be made sooner or later—he hoped it would be soon—was to find out what were the stresses which occurred when a body had passed its yield-point and got into a more or less plastic state. It was really the most interesting work that was outstanding in the subject of strength of materials. The forging of hot materials was one of those cases. Possibly it was more complicated than the case of a cold material because of the temperature conditions, but in any case, the distribution of plastic stress was a line of investigation which would have to be tackled almost immediately, if they were to obtain useful results with regard to cutting tools in which The Institution of Mechanical Engineers was so much interested.

Communications.

Sir HENRY FOWLER, K.B.E., Member of Council, wrote that he would be glad if Professor Coker would say whether he had made any experiments to note the effect of vibration on material or specimens while under stress, as, practically speaking, in all cases where structures were in such a condition, they were accompanied by some vibration, and if the effect of this, which was often great, could be shown, it would be of very considerable interest.

With regard to the floating surfaces in contact, could Professor Coker say to what degree of accuracy these surfaces were true. It seemed to be almost impossible to get a satisfactory flexible or semi-flexible substance to interpose between two surfaces in contact, as in nearly all cases the intermediate substance tended to "flow."

With regard to the illustrations which showed the excess of pressure on the edge of the block bearing on the larger surface, a considerable time ago in an effort to find a suitable substance to interpose between two surfaces, the writer used several sheets of hard paper; these were put on the top of an ordinary compression test-piece, and upon pressure being applied, it was found that the surfaces of the test-piece became concave, the paper being finally cut through all along the circumference of the test-piece, although its thickness in the centre was very little increased. This, he thought, bore out the illustrations which the Authors had given.

In connexion with the pressure that was applied through a V surface, what was the radius of the edge of this? He thought this had a very material effect on the stresses set up at the point of contact. He would also like to have further information with regard to the relative behaviour of xylonite and steel, and what was the composition of the Hadfield's steel mentioned in connexion with Fig. 19 (page 409). Steel was of course a very complex substance, and its behaviour depended very largely upon its composition.

Dr. W. H. **Hatfield** wrote that the Authors were to be congratulated on the useful application of the optical method of attack to important practical problems. They showed that so far as the mathematical results could be reduced to numerical values, the latter fully substantiated the results of the optical analysis, thus giving further confidence in the results for those cases which could be solved optically but not mathematically.

With regard to the value of results of tensile tests, the inaccuracies caused by putting centre dots or scratches on test-pieces, either for simple measurement of elongation, or for the purpose of carrying an extensometer, had long been felt to be serious, but just how far they interfered with the results obtained was hitherto a matter mainly for speculation. Professor Coker had now put the matter on a firmer footing. A simple way of translating the results from the small models to actual test-pieces, was to compare the stresses set up in the models by the transverse pressures with the longitudinal stresses that would have resulted if forces of equal value had been applied along the length of the specimen, remembering that generally, similar relative values would hold good for the ordinary test-pieces loaded similarly. Taking the figures given in Table 10 (page 418), the longitudinal stress due to a load W of 100 lb. would have been 500 lb. per square inch. The stresses set up when this load was applied transversely by knife-edges, varied from 249 to 431 lb. per square inch longitudinally, at the critical cross-section and from 920 to over 6,000 transversely, presumably reaching indefinitely high values in the neighbourhood of the knife-edges. On a tensile test-piece carrying extensometer of appreciable weight, (such as the Ewing type), it appeared then, that the material in the immediate neighbourhood of the knife-edges was seriously broken down, and the damage might extend an appreciable distance on either side. How far would this invalidate the extensometer readings? The distinct rounding-off of most load-extension curves just beyond the limit of proportionality was possibly exaggerated due to this cause, giving an apparent value for the limit, appreciably lower than the real one. The stress longitudinally due to the transverse pressure fortunately was relatively small compared with the stresses applied longitudinally in carrying out the test—the former being probably limited to say $\frac{1}{2}$ ton per square inch locally. This meant, however, that at best one could not depend upon proportional limit determinations to a much finer limit than $\frac{1}{2}$ ton per square inch. Would the Authors say whether, in their opinion, the inaccuracy was likely to be more than this? Would the fact that the transverse stresses, due to the clamping of the instrument, were much higher, cause still earlier yielding of the test-piece longitudinally, and so increase the error of the determinations of the limit of proportionality?

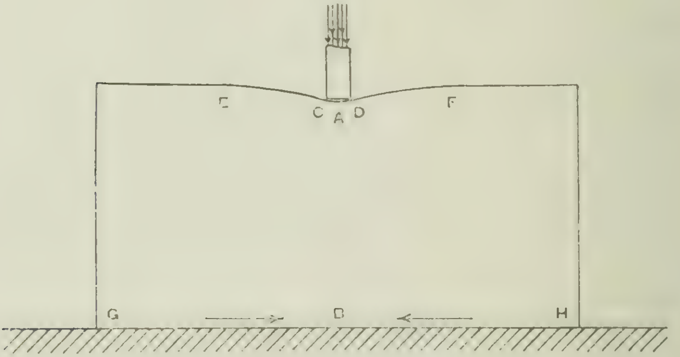
With regard to the form of test-piece employed by Professor Dalby, having collars turned with the piece, this seemed to be an improvement in every way on the ordinary method of centre-dotting. It was unfortunately outside the range of everyday practice.

The Authors referred to the stresses due to line contact in roller bearings, gear teeth, etc., and the writer hoped that in a further Paper on this subject, the Authors would deal with the local intensities of the pressures set up, and their distribution over the areas of contact, in such cases.

Dr. WALTER A. SCOBLE wrote that his association with Professor Coker when he commenced his researches by the use of polarized light, allowed him to appreciate the large amount of careful work, requiring delicate manipulation, which had been done in connexion with this Paper. It was probable that many members would not have time to study this long Paper in detail, and he would suggest that Professor Coker should add a conclusion to give the general results and to indicate their bearing on engineering practice If engineers would study these general investigations and picture the behaviour of the material which led to the results obtained, they would be rewarded by having a clearer understanding of the stress distribution in the complex cases which so often arose.

The Authors emphasized the fact that when a bar of material was supported on a slab and was subjected to a pressure at the centre of the top surface, the pressure between the bar and the slab was confined to the region near the line of the pressure and the ends of the bar bent upwards. Further, the pressure on the top of the bar was most intense at the edges of the surface on which the load was applied. These phenomena could be explained in a general fashion as follows: The compression in the direction AB, Fig. 34, was accompanied by elongations normal to AB. In the lower portion of the bar the elongations might actually occur, or, if this would involve sliding on the surface GBH, and the frictional resistance was great, the elongation was opposed by frictional surface shears in the directions of the arrows. No doubt there was lateral elongation in the region of the application of the pressure, but this was less than the increase of length required by the new shape of the indented surface, ECDF. Consequently there was a virtual shortening here under the load. The similarity to the case of a beam was evident,

Fig. 34.



compression above and elongation below, and so the ends of the bar canted up. The natural, continuous shape of the depressed surface was like ECADF, curved at all points except where the curvature changed sign. Excessive pressures at C and D were required to depress these points to the depth of A. A rigid base-plate of a column would exert more than the average pressure near its boundaries, but if the base-plate were not rigid the ends were relieved, and, in the case of insufficient stiffening, the pressure was greatest on the central region.

He was gratified to find that the lateral strain-meter which he introduced had been developed by the addition of slides and micrometers to control the position of the needles, and that with this addition the instrument gave records which permitted a more complete solution of the problems investigated than was furnished by the optical method alone. It was stated that, under tension stress, the law of optical retardation of nitro-cellulose compounds was proportional to stress and not to strain, and that it was linear, even when the material was stressed far beyond the elastic limit and very near the yield-point. Hence the optical measurements required no correction at high stresses. But surely, if the strain were no longer proportional to the stress, that fact caused the stress distribution to be altered, it was no longer similar to that in an elastic material under the same system of loading, such as steel. It appeared that the Authors measured the stress in the xylonite model, but at the places of high stress the distribution was only very approximately similar to what it would be in steel. But many materials had no better elastic properties than nitro-cellulose, so for them the agreement was sufficiently good.

It appeared to the writer that Professor Coker did not truly present the effect of centre dots on a specimen under a tension test. Contact pressure had little if anything to do with the fracture taking place through the dots. The case was more closely comparable with the notched bars previously investigated. Even so, in his experience, although the centre dots sometimes localized the fracture, particularly with the harder materials, the effect on the breaking stress was within the limit of experimental error. The effects investigated by Professor Coker were smoothed out after yield. The example given in the Paper corresponded to a pressure at the extensometer screws one-third the tension on the specimens. This corresponded to a very low tension on a metal specimen. The effect of the revised stresses on the elastic constants would be too small to be detected by an extensometer. At the elastic limit of a low tensile steel the initial screw-pressure was probably about one-hundredth of the tension on a standard specimen of 0·564 inch diameter. But the initial screw-pressure was reduced or disappeared through the lateral contraction of the specimen, because most extensometers had fixed and not spring-loaded screws. Immediately after yield, rigid clamps were often found to be loose in the centre dots. There seemed to be little doubt that the discontinuity at the centre dot, and not the pressure applied there, localized the fracture, and the fact that specimens of similar material marked for elongation measurements often failed in the same way supplied a confirmation of this view.

Mr. C. HUMPHREY WINGFIELD thought that the value of this highly mathematical Paper would be greatly increased if the Authors would summarize their conclusions in a form which could be easily made use of in general practice. He gathered that they would be somewhat as follows, but he hoped that the Authors could state them in a more definite manner and perhaps add to their number :—

1. It was of no use attempting to calculate the distribution of stress, as this could not " be determined except by experimental means " (page 365).

2. Lateral pressures of only 15 lb. transmitted by knife-edges to the sides of a 1-inch by $\frac{1}{10}$-inch test-piece materially altered the distribution of stress due to a longitudinal pull of three times that amount, the stress being greater in their immediate neighbourhood (page 412).

3. A mere scratch or indentation, although without continuance of lateral pressure, often altered the distribution sufficiently to determine the position of the fracture in high-tension steel

(page 407), or even when the material had become very plastic, Fig. 19 (page 409).

4. An increase of stress occurred near the enlarged end of a standard test-piece, which was met with under more advantageous circumstances (page 433), in the case of a thin flange such as used by Professor Dalby (page 420).

5. The radius of the fillet round such flanges did not matter much (page 430), nor was the form of curve, if other than a radius, very important (page 433).

6. In compression-tests uniform stress could not be approached : (*a*) unless the specimen was bedded on parallel blocks (page 406) of the same material ; (*b*) if the thickness was more than about one-quarter of the width (page 407).

Professor COKER wrote that he quite appreciated the suggestions made by Dr. Scoble and Mr. Humphrey Wingfield that in a somewhat lengthy Paper, a summary of the main conclusions might be useful, but, as the discussions in London and Manchester had shown that no difficulty had been experienced in understanding what these were, he had not attempted to add further descriptive matter. The surface effects in a loaded block no doubt contributed much to the changes in the form of the block, and Dr. Scoble emphasized their importance, possibly unduly so, having regard to the colour effects observed in the body of the block shown in Fig. 11, Plate 16.

The writer also desired to acknowledge the help of Dr. Scoble in devising a simpler form of extensometer to that which he used originally for lateral measurements of metals and rocks* under stress. There seemed some ground for supposing that, for very high stresses, there was some redistribution of stress even when the law of optical effect held. If this was so, it afforded an explanation of some small discrepancies between calculation and experiment which had been observed in one or two cases in which along a given line there was an extremely great stress variation, which latter, when measured by optical means, was found to agree within one or two per cent along the whole line except at the very highest points, when differences in defect of from 4 to 5 per cent were measured. Allowing for possible experimental errors these results seemed to indicate a stage at which equalization was commencing. Dr. Scoble appeared to be under some misapprehension as to the points raised in the Paper regarding the harmful effects which might be caused by extensometer screws. It was clear that these effects arose, in general, from the permanent indentations, and this was especially emphasized by the description of the test on "Hadfield" steel, in which the cross-sectional area was finally about 43 per cent smaller than the original cross-section, except at the fracture, where it was even less. Further, it would be noted (Fig. 19, page 409) that the load at which the extensometer was removed was about one-third of the breaking load.

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* "A Laboratory Apparatus for Measuring the Lateral Strains in Tension and Compression Members, with some Applications to the Measurement of the Elastic Constants of Metals," by E. G. Coker. Proc. Roy. Soc. Edin., vol. xxv, 1904–5.

"An Investigation into the Elastic Constants of Rocks, more especially with reference to Cubic Compressibility," by Frank D. Adams and Ernest G. Coker. Carnegie Institution of Washington, 1906.

Dr. Hatfield raised the question of the influence of the indentations upon the form of the load-extension curve, and especially the effect on the limit of proportionality, and on the form of the curve just beyond this point. There was no doubt that indentations tended to change the limit of proportionality in their neighbourhood, and their influence increased with decreasing gauge length. It was evident from Fig. 21 (page 414), that the conditions in that case were of such a character that simple stress distribution was not obtained for a length of the specimen at least equal to its width in the neighbourhood of the applied transverse load, and as extensometer readings were a summation of the alterations of form over the whole gauge length measured in the axial direction, it seemed evident that the lowering of the limit of proportionality would depend on this length and become more marked as it decreased. The cross-sectional shape and area also introduced other variable factors. It seemed probable, therefore, that given conditions in which these variables could all exert their maximum influence together, it would be quite possible to obtain a limit of proportionality much more than half a ton per square inch below its true value, accompanied by an abnormal rounding off of the load extension curve beyond this limit.

As regards vibration effects mentioned by Sir Henry Fowler, no measurements had been made as yet on their influence. The flat contacting surfaces were true planes within one or two ten thousandths of an inch, and were prepared by the usual scraping processes. The effect of hard paper on the end surfaces of compression blocks was very interesting, and it was worth noting that the writer had obtained the same type of effect with nitro-cullulose blocks under similar conditions. The V knife-edges were made by grinding the inclined surfaces, and the edges produced were similar in character to the steel knife-edges sometimes used in precision balances, but the radii of curvature of the edges were not measured, and as these pieces had been used for other work since, it is now impossible to say what their exact condition was when the measurements were made. The relative behaviour of xylonite and steel was difficult to describe briefly, but fortunately these matters had been examined recently * in such a manner that an effective comparison could be made.

Lastly, the writer was informed by Sir Robert Hadfield that the composition of the test bar A8725 was as follows:—

Iron	86·09	per cent
Manganese	12·64	,,
Carbon , . . .	1·27	,,
	100·00	

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* "Researches on the Elastic Properties and the Plastic Extension of Metals," by Prof. W. E. Dalby, F.R.S. Phil. Trans., 1920.

"The Stress-Strain Properties of Nitro-Cellulose and the Law of its Optical Behaviour," by Prof. E. G. Coker, F.R.S., and K. C. Chakko, M.Sc., Phil. Trans., 1920.

The Institution of Mechanical Engineers.

PROCEEDINGS.

April 1921.

An Ordinary General Meeting was held at The Institution, London, on Friday, 22nd April 1921, at Six o'clock p.m.; Captain H. Riall Sankey, C.B., C.B.E., R.E., ret., *President*, in the Chair.

The Minutes of the previous Meeting, held on 18th March, were read and confirmed.

The President announced that the following 49 Candidates had been duly elected:—

MEMBERS.

Danielsen, John William,	Birmingham.
Garcke, Sidney Emile,	London.
Leech, William,	Glasgow.
Nielsen, Holger Lundsgaard Raaschon,	Hankow.

ASSOCIATE MEMBERS.

Brown, William,	Erith.
Cowan, Wellwood,	Wakefield.
Evans, Evan Reginald, M.B.E.,	Singapore.
Fletcher, Robert Mason,	Tabaquita.
Genève, Louis Frederick Charles Anthony,	London.
Griffiths, Edward,	London.
Hanford, Rupert,	London.
Hartley, Ellis,	Keighley.
Hastings, Herbert Joseph,	London.
Jones, Arthur William,	Birmingham.
Miller, John Francis Xavier, Captain, R.A.O.C., I.O.M.,	Harwich.
Mills, Sidney Ewart,	Radcliffe.
Mitchell, Raymond James,	London.
Peck, Henry Adams, Captain, R.E.,	Salisbury.

Reeve, William Alexander,	London.
Renfrew, John MacKinnon,	Havana.
Renton, Gavin Alston,	London.
Richardson, Percival, Captain, R.E.,	Deolali.
Robertson, Harold John, Captain, M.C., R.A.S.C.,	Dublin.
Roscoe, Herbert James,	London.
Sims, George Arthur, Captain, R.A.S.C.,	London.
Walter, Rees Christmas,	Colchester.
Whitehead, Robert Wood,	Dera, Ismail Khan.

ASSOCIATES.

Bidmead, Percival William,	Jesselton.
Hilborn, Frank Albert, Captain, R.E.,	Wool.
Pemberton, Samuel Thomas,	Birmingham.

GRADUATES.

Barrell, Kenneth Cecil,	Coventry.
Beale, Albert,	London.
Bunclark, Frederick Thomas,	London.
Burnet, Harold,	Manchester.
Clark, James d'Argaville,	London.
Cooke, Arthur Ellis Owen,	London.
Das, Akshaya Narayana,	Glasgow.
Glen, Alexander Ernest,	Glasgow.
Goodman, Reginald Terence Wynne,	London.
Gould, Alfred John,	London.
Hinds, Colton Richard,	Doncaster.
Hudson, Albert,	London.
Lloyd, William Francis,	London.
Ord, Thomas Charles,	Newcastle-on-Tyne.
Plunkett, Patrick Archibald,	London.
Reid, William Alfred,	London.
Renton, George Frederick,	Bradford.
Smith, Douglas Buchanan,	London.
Smitz, William Bennett,	London.

The President announced that the following five Transferences had been made:—

Associate Members to Members.

Dabell, Alexander Frank,	London.
Dew, Joseph Turner,	Antigua.
Nell, Leonard,	Lagos.
Robertson, James French,	Antwerp.
Thompson, Joseph,	Tokyo.

The question of "Limit Gauging" was introduced by Sir RICHARD T. GLAZEBROOK, K.C.B., Sc.D., F.R.S., *Honorary Life Member*, and discussed by the Meeting.

The Meeting terminated shortly after Half-Past Seven o'clock. The attendance was 104 Members and 29 Visitors.

The discussion on "Limit Gauging" was continued at:—

LEEDS, in the Philosophical Hall, Park Row, on Monday, 2nd May, at 7.30 p.m.; Lt.-Col. E. KITSON CLARK, *Member of Council*, in the Chair.

LIMIT GAUGING.

Note by Sir RICHARD T. GLAZEBROOK, K.C.B., Sc.D., F.R.S.,
Honorary Life Member.

(1) *The Basis for Standardization.*—The Hole or the Shaft; reasons for selecting the Hole. The Shaft necessary for some work.

(2) *The Unilateral and the Bilateral Systems:*–

- (*a*) The Unilateral System. Its use in the original Engineering Standards Report. The nominal dimension as the dividing line. All tolerances on Holes positive. Clearance equal to Allowance + sum of Tolerances. The use of standard Plug Gauges. Its adoption in Germany and Switzerland.
- (*b*) The Bilateral System. Its adoption by a number of Firms.
- (*c*) Comparison of the two; the possibility of a combination. Mr. Hedley Thomson's suggestion. The Continental arrangement. Resolution of the Limit Gauges Panel.

(3) *Systems of Limits:*—

- (*a*) Standardization of a series of Tolerances.
- (*b*) The quantity to be dealt with. Allowance + sum of Tolerances. Allowance = Minimum Clearance for satisfactory working. Sum of Tolerances = additional possible clearance to permit wear and tolerate imperfect workmanship.
- (*c*) Limits applicable to work; the question of Tolerances on Gauges.
- (*d*) The relation between Limit and Diameter—

$$\text{Limit} = \text{Nominal Size} + a + b\sqrt{D} + cD.$$

- (*e*) Limit Lines as given by the above; Steps and Ranges; their necessity.

(4) *Steps and Ranges.*—The Values of these :—

(*a*) The unit step 0·0005 inch or 0·0004 inch. Steps, except for fine work, multiples of one or other of these. The convenience of equal steps.

(*b*) The ranges ; their lengths fixed by that of the steps.

(*c*) Mr. Hedley Thomson's Scheme. The Steps are given by the expression—Limit $= r\,(1 + n)$,

n being the number of the range and r some suitable integer ; the Ranges by the series—

$1,\ 1 + 2,\ 1 + 2 + 3\ \ldots\ldots\ldots\ldots\ldots\ 1 + 2 + \ldots\ldots\ldots + n.$

Thus the nth range

$$= 1 + 2 + \ldots\ldots\ldots + n = \frac{n\,(n + 1)}{2}$$

the units being any convenient quantities, e.g., for r 0·0001 inch, and for the ranges 0·1 inch.

(*d*) Number of Ranges required :—

(i) Mr. Hedley Thomson's Scheme.
(ii) Continental Schemes.
(iii) Other Suggestions.

Desirability of a scheme.

(5) *Limit Lines.*—Their applicability. Interchangeable work and the requisite conditions

(i) Running Fits.
(ii) Transition Fits.
(iii) Interference Fits.

(i) Running Fits—General agreement as to possibility ; questions as to amounts of tolerance, etc.

(ii) Transition Fits—Difference of opinion as to possibility ; necessity for close limits. In a given case, the clearance may be (*a*) positive, (*b*) negative, and still be within the limits.

(iii) Interference Fits—Question as to the proper law for the allowance.

Can the last two be standardized ?

(6) *Illustrations of Systems of Limits.*

Discussion in London on Friday, 22nd April 1921.

The President said the Members would recollect that Limit Gauging was the subject matter of Sir Richard Glazebrook's Thomas Hawksley Lecture.* Subsequently the wish was expressed that a discussion should take place on certain points dealt with in it. Sir Richard was approached on the matter and had very kindly consented, he feared at much inconvenience to himself, to open a discussion on the present occasion, and for that purpose had prepared a note which was in the hands of the Members. He would ask Sir Richard to be kind enough to open the discussion.

Sir Richard T. Glazebrook, K.C.B., F.R.S., said that the first matter to settle was the basis for standardization. It was understood, he thought, that they were concerned practically entirely with the standardization of cylindrical work, and the question to be considered was whether the hole or the shaft was to be taken as the basis for that standardization, that is, was the hole to be the part that approached most nearly to the nominal dimensions and were the allowances which were required to secure proper fit in the case of a running fit to be made on the shaft, or should that basis be reversed ? It was now practically agreed that for nearly all kinds of work the hole was the proper basis to take, although there were certain kinds of work, shafting, for example, for which it was necessary to treat the shaft as the basis and to make the allowances, etc., on the hole. Assuming then that the hole was to be the basis, was the standardization to proceed on the unilateral or the bilateral system of gauging ? Fig. 1 (page 476) would illustrate the difference.

The Fig. represented the section of a shaft and hole, and the lines AB, etc., defined the positions of the minimum and maximum hole and the minimum and maximum shaft. The question at issue was which of those various lines shown in the diagram should be taken as the nominal dimension. It had been agreed that the hole should be the basis, and therefore one of the lines relating to the hole should be considered as of nominal size. On the unilateral system the line that was taken as approaching nearest to the nominal size was the line XY, coinciding with AB, the minimum hole. All tolerances on the hole were positive. In the bilateral system, on the other hand, some line, such as X^1Y^1, lying between AB, the minimum hole, and CD, the maximum hole, was taken as of nominal size. The tolerances were both positive and negative. The first point for settlement was which of these two systems was to be adopted. Going back to the original Report of the Engineering Standards Association, the shaft was there taken as a basis, but the Report was worked on a unilateral system, the tolerances on the shaft were negative, and the allowances made on the hole were positive. The nominal dimension was the dividing line. In a unilateral system based on the hole the tolerances on the hole were positive; the maximum clearance between the hole and the shaft was equal to the allowance, together with the sum of the tolerances, while the minimum clearance was the allowance.

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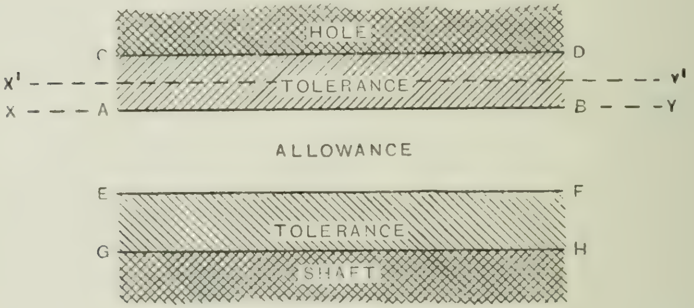
* Proceedings, I.Mech.E., 1920, page 1075.

FIG. 1.—*Minimum or Mean Hole.*



He did not propose to say very much about the argument for and against that system, but merely to call attention to the difficulties. Those who had been in the habit of using a series of standard plug-gauges and not working to limits had practically adopted the unilateral system as their basis. The unilateral system had also been adopted in Germany and Switzerland and had practically been adopted in America. It was also adopted in this country for screw-gauges, only in connexion with the screws the shaft was the basis. The nominal size was the maximum dimension of the screw. The matter had been discussed to a considerable extent by the various Panels and Committees of the British Engineering Standards Association, always with the result that there had been a small majority in favour of the adoption of the unilateral system, but a majority so small that it was difficult to act on it without further authority. The position was that at present nearly all those who approached the question *ab initio* would say that the unilateral system was the one to adopt. On the other hand, the bilateral system had been adopted in England by a number of firms using limit gauges, and therefore there was very considerable difficulty in their changing or in adopting a system which such firms would be compelled to take if they wished to fall in with the standard method of gauging work. However, at the last meeting of the Committee which dealt with the matter the following resolution was come to: "That the unilateral system be the only system recommended as standard in the Report, but that reference be made to the bilateral system, indicating the manner in which this can be used in conjunction with a series of shafts and suggesting a method of giving effect to this." The Committee came to the conclusion that it was possible to standardize a series of shafts which could be employed satisfactorily either in a unilateral hole or in a bilateral hole. It would be necessary, in the case at any rate of the closer fits, that the shaft that was used for a close fit on the one system should be used for a less close fit on the other system; but the same series of shafts, it was hoped, could be used in both systems, and he believed that would be found to be the case. The suggestion made, therefore, was to adopt as standards a series of shafts and to leave the question of the hole to settle itself in the future. If an agreement could be come to now, however, he thought it would be very much better to settle once for all that one system or the other should be standard, and try to arrange in the same way that those who were using the other system should in time fall in with the standard method. That, he might say, was the method that had been adopted in Germany. A meeting was called of those who were using the bilateral system, and they came to the conclusion that on the whole the evidence in favour of the unilateral system was so strong that they were prepared to give way and at any rate make an attempt to put their works on to the unilateral system and have one system. It was so arranged, subject to the condition that at the end of some limited period—two years, he thought it was--the matter would be again re-opened.

The next question to be considered was the system of limits and the quantities to be dealt with, namely, the allowances and the tolerances. It had been suggested that it might be sufficient at present to standardize the series of tolerances and allowances, to say that for work of a certain description close tolerances of $\frac{\frac{1}{2}}{1000}$ inch would be satisfactory, and that for other sorts of work tolerances of $\frac{1}{1000}$ inch and so on should be used, and not to attempt any general scheme connecting tolerances and allowances with diameter. He thought it would be felt that that would not be satisfactory, because it would not give to the user sufficient information as to the kind of limits that were advisable for various classes of work.

It should be noted that the limits considered were limits applicable to the work. That raised the important question as to how the work and the gauges that would be used for testing the work were connected. The matter was discussed in the Thomas Hawksley Lecture.* He merely wanted at present to call attention to the fact that the effective tolerance on the work was somewhat reduced by the tolerances allowed on the gauges.

The next question to be considered was the relation that must exist between the nominal diameter and the limits. The tolerances and the allowances would vary with the diameter of the work: according to what law would they vary? That was investigated a number of years ago in a series of experiments made by Mr. Attwell of the National Physical Laboratory. At that time the Committee then sitting under the chairmanship of Sir Frederick Donaldson had before it a good deal of information from various firms, in particular from Messrs. Armstrong, Whitworth and Co. It appeared that they were working to a relation which made the tolerance proportional to the square root of the diameter. Mr. Attwell's experiments led to much the same result, so that the following formula was obtained as the relation between any limit and the diameter: Limit $= a + b\sqrt{D}$. For certain purposes it might be necessary to have tolerances or interferences proportionate to the diameter, and that would give another term: $+ cD$. Most of the schemes of limits that had been used had been based on that law, the quantities a, b or c being different according to the class of work and nature of the fit, one or other of them in certain cases being zero. Dealing with running fits, which were perhaps the more important, then coefficient c was zero, and the limit that was worked with was usually one given by the expression $a + b\sqrt{D}$. If a curve was drawn in which the diameters were measured horizontally and the limits vertically, a parabola was obtained. It was impossible to alter the limits for each small change in diameter, and therefore the parabolic curve was replaced by a series of steps Then the tolerance remained constant over a series of ranges of lengths of diameter.

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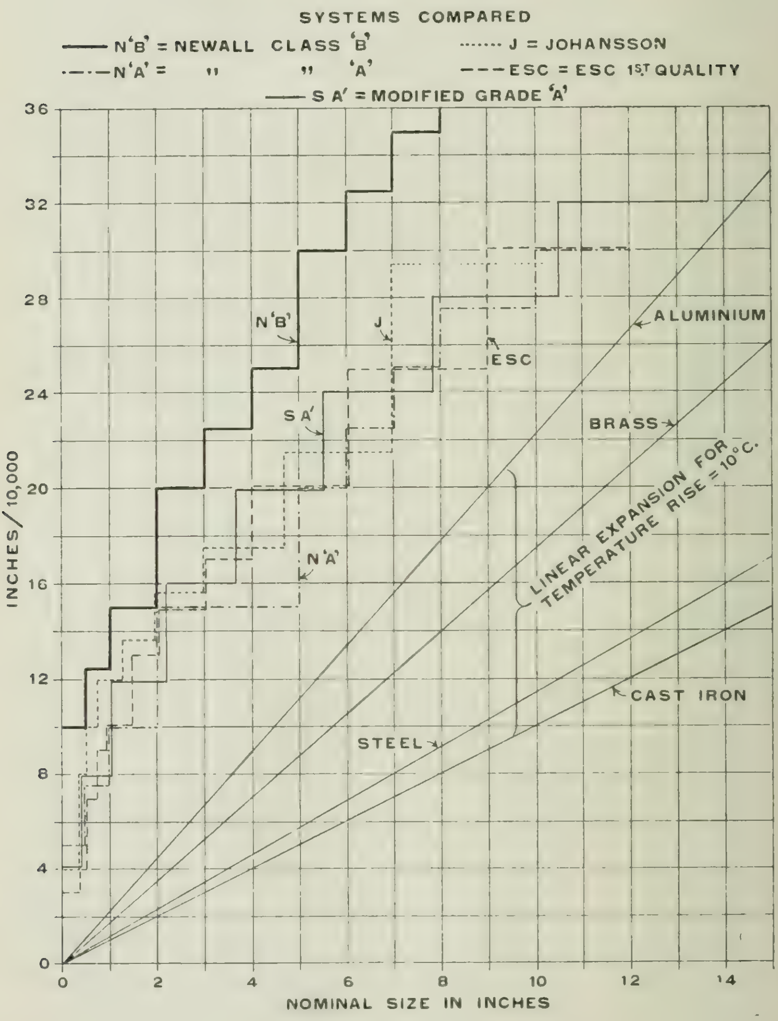
* Proceedings, I.Mech.E., 1920, Fig. 11, page 1101.

The next important question related to the size of the steps and ranges. There were various reasons partly of convenience and partly on other accounts, which he had no doubt some of the speakers would deal with, why the steps should be of uniform length. If they were, then the fact that the limits were given by a parabolic curve fixed the length of the ranges. The lengths of the steps and ranges were thus determined. He had indicated in his summary (page 474), the actual formula that gave the relation between them, and it was explained more fully in his Thomas Hawksley Lecture. Those steps and ranges agreed very fairly with those in quite a number of the limit systems that were now in use.

He desired to call attention to the fact that the various schemes all led to limits of much the same amount. Fig. 2 (page 480) showed a number of systems. It would be noticed that in all the steps and the ranges agreed fairly closely, so that the size of the step and the range seemed to be generally agreed upon. He thought more would be heard with regard to that very shortly. It was necessary then to settle the number of ranges required, and to determine the class of

FIG. 2.—*Limit Systems, Hole Tolerances.*



fit to which those various ranges were applicable. The fits included running fits, transition fits, and interference fits. While he thought it would be found there was not much difference of opinion as to the applicability of a limit system to running fits and the possibility of obtaining of interchangeable work, it would be found also that when dealing with transition fits and interference fits other difficulties arose and the problem was much less simple than that of devising a system only for running fits.

He suggested that the points to discuss were first the question of the unilateral and the bilateral systems, then the question of the size of the steps and ranges, and, perhaps before that, but at any rate at the same time, the question of the applicability of any sort of system of limit gauging to interference fits and to transition fits. In settling all the questions of tolerances and allowances in limits, it was convenient and desirable to have some recognized unit to work to. It would be noticed under heading 4 (page 474), that two suggestions had been made, one that the unit step should be $\frac{5}{10000}$ inch—that was said to be convenient for use with a micrometer—and the other that the unit step should be $\frac{4}{10000}$ inch. That had its advantages in the fact that it was an even number of ten-thousandths, and further that it was possible to change from the inch tolerances to the metric tolerances without much difficulty, because $\frac{4}{10000}$ inch for that purpose was the same as $\frac{1}{100}$ mm., and the figures that were obtained in inches were easily and directly transferable into metric units when wanted.

The President said he was sure the members desired to express their thanks to Sir Richard Glazebrook. It was very much to be desired that the discussion should help materially towards settling the difficult points that Sir Richard had referred to, and he would therefore ask the speakers to be as little discursive as possible and to limit their remarks to the questions of the unilateral and bilateral systems and to the steps and ranges.

Mr. William Taylor, O.B.E., (Member of Council), said that for seventeen years he had worked with others on the Standards

Committees in dealing with the subject of limit gauges, and of late he had come to feel that they had been ploughing the sand, because very little had been accomplished. At the present time the position was that Sir Richard Glazebrook was in charge of a series of Committees, Panels, and sub-divisions on the subject, which had been battling for two years, trying to arrive at a decision, which was delayed because the Committees were divided into two camps, which he would characterize as the academic and the practical. Personally, he tried to represent the practical side, and he had attended the Meeting hoping that the members, who he believed were mostly practical men, would back up those members of the Committee who were fighting the battle on their behalf. If he did not receive any encouragement from them, he felt like giving up the subject and turning his attention to other matters. What was needed in all standardization was simplicity, but, in the case of limit gauging and the subject of tolerances and allowances, a question was being dealt with that was so complex that it was very difficult to discuss it

It had always seemed to him that there was the same kind of difference between the unilateral and the bilateral systems as there was between truth and falsehood. There could be but one true statement in respect to any subject. Every subject had many aspects, but there was only one complete statement which was strictly true, whereas an indefinite number of false statements might be made. The unilateral system, established by Whitworth, who introduced standard plug and collar gauges, had been followed for two generations. Thousands of engineers were using that system at the present day, in order always to ensure that the shaft was never larger than the nominal size, and that the hole was never smaller. The shaft might be smaller, or the hole might be larger, if an allowance was wanted for a lubricant. In the bilateral system, either the hole or the shaft was allowed to have its limits straddling the nominal size, for example, the hole might be either larger or smaller than the nominal size. Where was the line of division between the shaft and the hole ? It might be anywhere according to choice, and therefore it was possible to have an indefinite number of bilateral systems, just as it was possible to have an indefinite number of false statements regarding any fact. He could not think that English engineers were going to throw overboard the work of Whitworth and establish a bilateral system of limits for shafts and holes. Mr. Hedley Thomson, a man of great ability, sent him at one time a list of the advantages of the bilateral system. He looked it through very carefully to see if it contained any very strong argument, but he did not find one. What he did find was that the bilateral system Mr. Hedley Thomson was now recommending was not a bilateral system which anybody used at the present time, so that the proposal was to set up still another bilateral system, and he could not think that the Committee would really do that.

With regard to the question of tolerance on gauges, seventeen years ago he proposed to the Standards Committee that it should consider tolerance on gauges as well as tolerance on the work, but the proposition was not accepted. It was practical experience during the War that compelled the Committee to consider tolerances on gauges, but they had not yet considered it fully, because, so far as they had gone hitherto, they had considered tolerance only in the making of a gauge, and did not give tolerance for the wear of the gauge When Sir Richard Glazebrook and the National Physical Laboratory inspected gauges during the War, they followed this arrangement: namely, that they paid just as much for a gauge which was potentially worn out, as for a gauge which had a full life, for the whole of the tolerance on the gauge was applied to the making of the gauge and nothing whatever was allowed for wear. They got into trouble, and the time would come when they would have to consider the tolerance for the wear of a gauge.

With regard to the steps, it was proposed that the tolerances should step up, as Sir Richard Glazebrook had indicated, by equal increments. That seemed to him to work in the following manner. The unit for buying butter in a poor district was, say, 4 oz. But the man who bought butter wholesale did not use 4 oz. as his unit; he dealt in large quantities and used a unit which was proportionate in some degree to the quantity that he was handling. The Committee, however, proposed that while the tolerance was small, the steps should be sometimes 100 per cent, that is, if they started with a tolerance of $\frac{1}{4}$/1,000, which most of the members knew was attainable with the modern grinding machine, when the step up was made the next tolerance was $\frac{1}{2}$/1,000. That was quite a practicable thing. But for large diameters the proposal was that they should also step up by those little increments, the result being that in the Report there were something like 100 or 150 different tolerances, when most practical men got along very well with four or five. Those who knew him and his business were aware of the fact that he was not one to decry the value of mathematics, because in his business mathematics were used as much, if not more, as in any branch of engineering, but he regarded mathematics as a means to an end and not as the end itself. Personally, therefore, he did not like the idea of the ranges strictly following a formula, so that the limit between one range and the next was defined by 3·59, or some odd figure which no practical man could remember. He wished to disabuse Sir Richard Glazebrook of the idea that every draughtsman who was worth anything spent a large part of his time in solving equations, and that, if he decided to have a 3-inch Whitworth screw, instead of looking in his tables or searching his memory to ascertain whether it had sixteen threads to an inch or not, he would solve an equation. That was not the way practical work was done. Simple tables and simple figures were required. A formula should be used in arranging a series of standards in order to get harmony and proportion in the series, but, having done that, the right thing to do was to put the formula in an Appendix to the Report—to bury it if they liked—and practical men would then forget all about it.

Mr. ROBERT DUMAS said he rose to support very largely the view that had been put forward by Mr. Taylor, at any rate, in so far as the choice of the unilateral hole was concerned. He thought the initiation of the first limit system was brought about by the theoretical engineer, to whom Mr. Taylor had referred, rather than by the shop man. The " armchair " engineer had in his mind the idea that he wanted to get the hole just as near as possible to the actual standard dimension, and knowing that, generally speaking, the hole was a little larger than the go-in gauge, he decided that the go-in end of the gauge should be a little smaller than the standard size. That was the man, he thought, that had to be blamed for all the trouble which the British Engineering Standards Committee, and the engineering industry as a whole, had to contend with at the present time over this particular question. If he had been content to build up his practice upon that then existing in the shops, he was perfectly satisfied that at the present time a uniform limit gauge system would have been in current use by the great majority of the engineering concerns in this country. Although it was late, he still thought engineers ought to have sufficient courage to go back and to build up their limit systems on the unilateral basis, which ought to have been done in the first instance.

It seemed reasonable that there should be one line in a system of limits coincident with the standard dimension, because that made clear thinking about the whole system so much more easy, and not only that, but it made the dimensions on the drawings so very much more informative, since, if a shaft was taken for a running fit and the maximum dimension of it was taken, it was always known that the difference between that dimension and the nominal was the minimum running clearance provided for. This, he thought, was of value both to the draughtsman and to the people in the shops who were using the system of limits. In the present days of mass production, when every influence was generally towards the deadening of interest in work, he thought it was necessary to put matters in such a way into the hands of the people in the shops that they might be as informative as possible, so that the men would take a real interest in and know what they were doing. From that psychological standpoint, he submitted it was desirable that as much simplification as possible should be introduced by having one of the dimensions on the standard line. If it was agreed that that was desirable, then he thought the balance of argument was decidedly in favour of having the minimum hole as the nominal dimension.

With regard to the system of ranges and range factors, he did not feel so alarmed as Mr. Taylor. He rather looked at the matter from the standpoint that it was desirable that they should have as big a tolerance with regard to any particular piece of work as possible. If they were going to keep the tolerance up to a maximum, it meant that that tolerance must vary by small increments as the diameter varied. If a particular piece of work was being dealt with which had to have a certain kind of fit, a limit gauge was required which had two dimensions, and it did not seem to him to matter very materially whether those two dimensions had to be expressed by three or four figures after the decimal point. If, however, it was thought there were too many steps introduced by means of the range and range factor system, he thought the objections might fairly well be met by plotting the limit lines, as given exactly by the formula originally suggested by Mr. Hedley Thomson, on a piece of paper on which various limiting lines were placed. That would mean that, for certain dimensions, the lines given exactly by the formula would be shifted a little bit up or down, but would give practically the same result from a workshop standpoint. It would then be possible to limit the number of dimensions used to steps varying either by $\frac{2}{10000}$ inch or $\frac{4}{10000}$ inch, or even perhaps $\frac{8}{10000}$ inch, when bigger allowances and tolerances were being dealt with. He thought Mr. Taylor's point could fairly well be met by a suggestion of that character.

With regard to the size of the step to be utilized, he supported $\frac{2}{10000}$ or $\frac{4}{10000}$ inch, in view of the very simple relation which existed between those dimensions and $\frac{1}{100}$ mm.; the relation remained sufficiently exact for all workshop purposes over the range of dimensions which came into consideration so far as tolerances and allowances were concerned.

Mr. HEDLEY J. THOMSON stated that his connexion with the practical application of limit gauges dated from 1903 when he was sent by Sir Charles Parsons to Berlin to investigate and report upon the limit system in use at the works of Ludwig Loewe and Co That firm, renowned for excellency of workmanship, even at that date used limit gauges for all its manufactures. The system was a bilateral hole basis system. His subsequent experience, before accepting the position of Technical Advisor to The Newall Co.

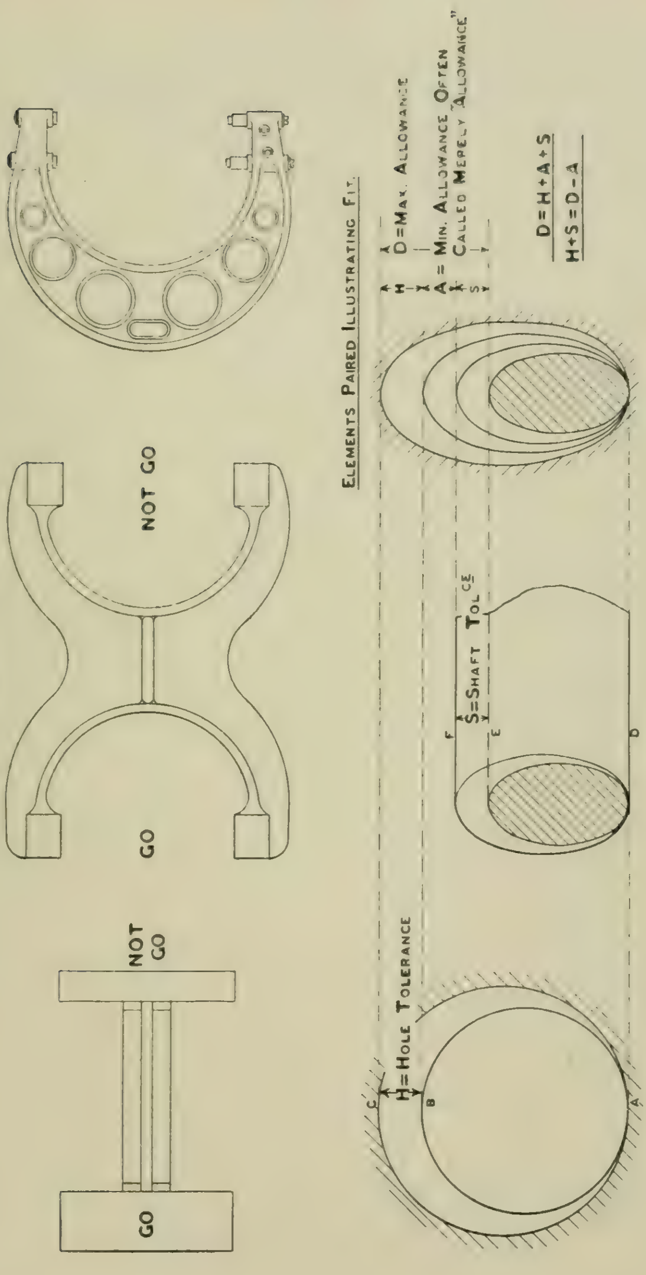

GO
NOT GO
GO
NOT GO
ELEMENTS PAIRED ILLUSTRATING FIT.
D=MAX. ALLOWANCE
H
A = MIN. ALLOWANCE OFTEN CALLED MERELY "ALLOWANCE"
S
D=H+A+S
H+S=D-A
S=SHAFT TOLCE
F
E
D
H=HOLE TOLERANCE
C
B
A

Fig. 3. *The Elements of Limit Gauging.*

Fig. 4.

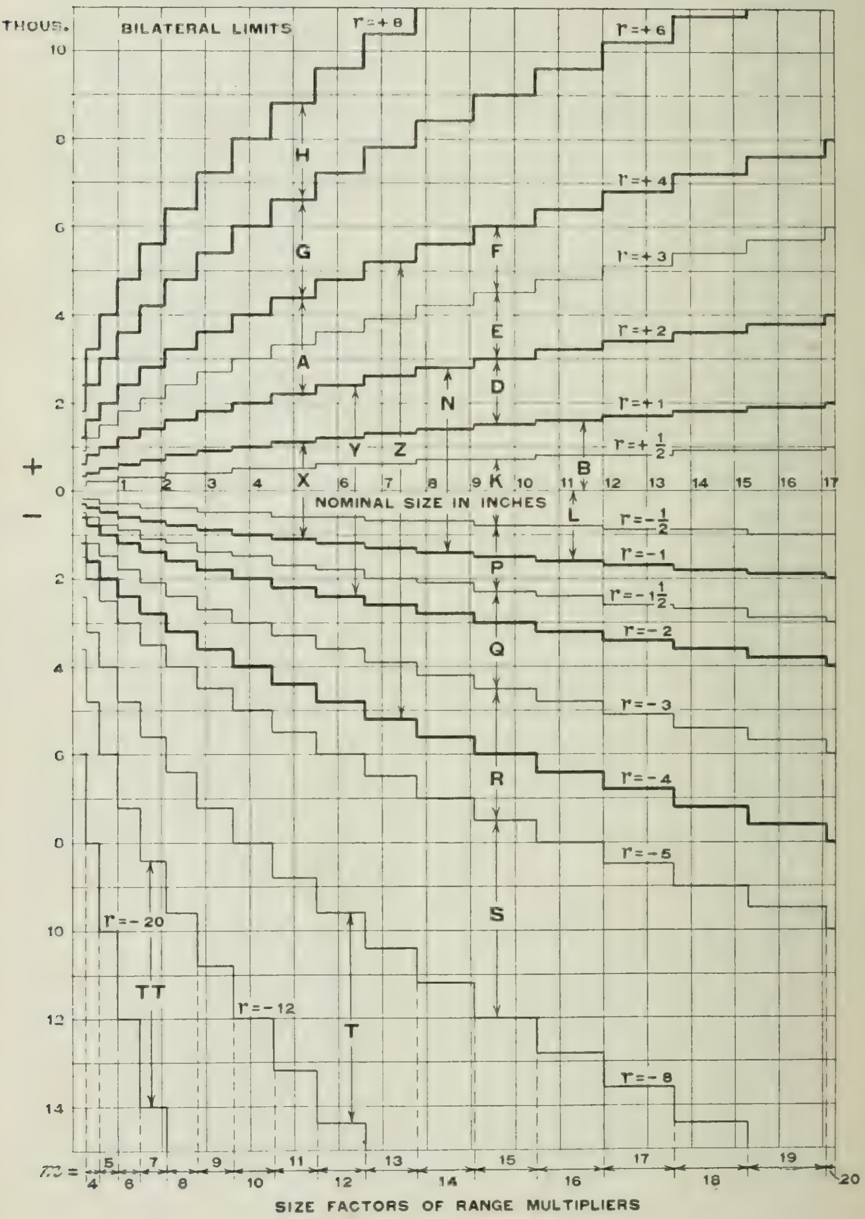
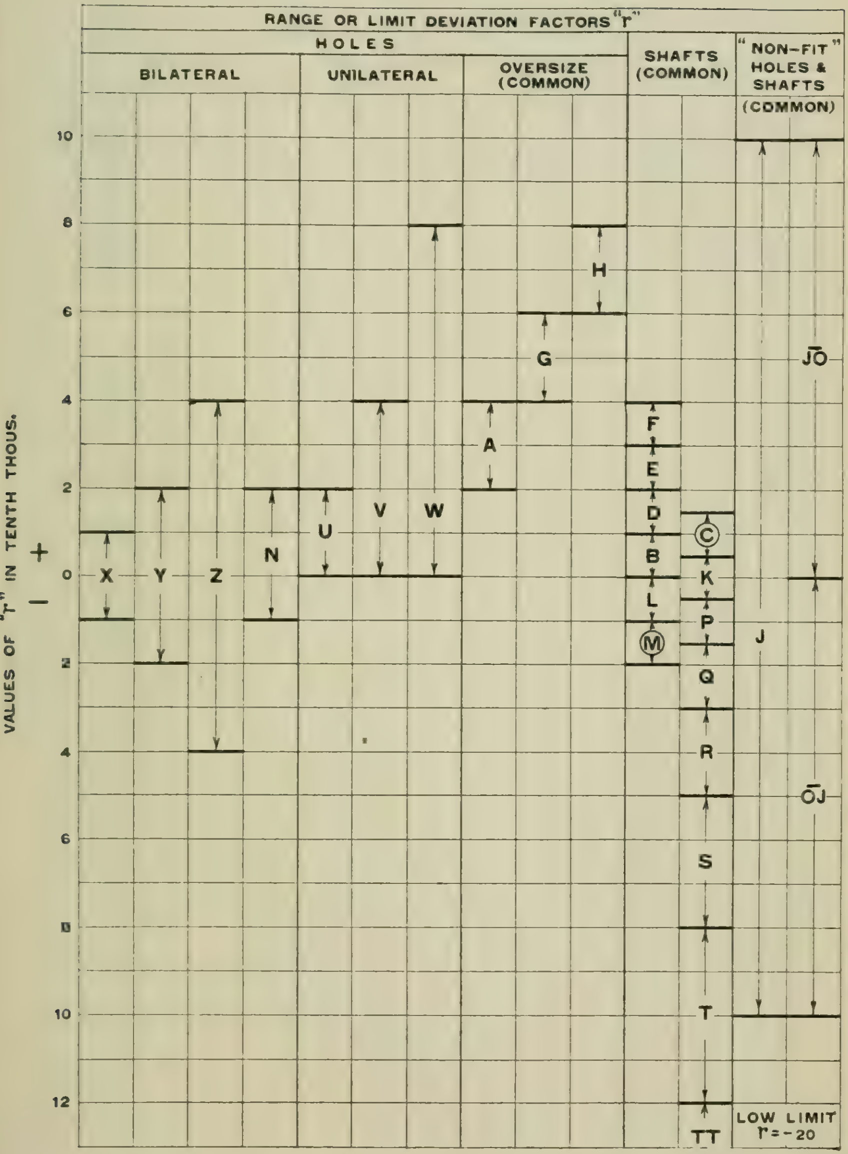

THOUS.
BILATERAL LIMITS
r = + 8
r = + 6
r = + 4
r = + 3
r = + 2
r = + 1
r = + ½
r = − ½
r = − 1
r = − 1½
r = − 2
r = − 3
r = − 4
r = − 5
r = − 8
r = − 12
r = − 20
H
G
A
X
Y
Z
N
F
E
D
K
B
L
P
Q
R
S
T
TT
+
−
10
8
6
4
2
0
2
4
6
8
10
12
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
NOMINAL SIZE IN INCHES
m =
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
SIZE FACTORS OF RANGE MULTIPLIERS

Fig. 5.


RANGE OR LIMIT DEVIATION FACTORS "r"
HOLES
BILATERAL
UNILATERAL
OVERSIZE (COMMON)
SHAFTS (COMMON)
"NON-FIT" HOLES & SHAFTS (COMMON)
VALUES OF "r" IN TENTH THOUS.
+
−
10
8
6
4
2
0
2
4
6
8
10
12
X
Y
Z
N
U
V
W
A
G
H
F
E
D
B
L
Ⓜ
Ⓒ
K
P
Q
R
S
T
TT
J
J̄O
ŌJ
LOW LIMIT r = −20

towards the end of 1919, covered the practical application of limit gauges in the manufacture of agricultural machinery, steam-turbines, automobile and aero engines.

Based on this and even more varied experience with the Newall Co., he had come to the conclusion that it was practically impossible for any one person, much less a committee, to settle satisfactorily what particular limits should be used in any particular case, without knowing beforehand all the special conditions obtaining, and that the most that any standard system could provide was a suitable series of limit lines supplemented by a broad indication as to what results under ordinary conditions were likely to be achieved by stated combinations. In nearly every machine certain fits must be accurate, and therefore it was impossible to divide up the grades into separate sections exclusively applicable to different manufactures. If that view were taken, then much time would be saved by avoiding unnecessary and lengthy discussions as to the exact effect of fits.

In applying limits to any existing manufacture, he had found that the simplest plan was to measure maximum and minimum clearances of fits in finished products passed as "good enough" and ready for sale. Guided by the relation shown on Fig. 3, namely, that the difference between the maximum and minimum clearance was equal to the sum of the tolerances, it was not a difficult matter to decide upon suitable tolerances. It was his opinion that the present B.E.S.A. proposals provided a sufficient choice of limits and tolerances to suit almost if not all classes of engineering. Figs. 4 and 5 covered the complete range of holes and shafts embodied in those proposals. Fig. 4 dealt only with bilateral holes and the shafts to pair with them, while Fig. 5 gave values of range or limit deviation factors for all holes and shafts whether used in the bilateral or unilateral arrangement. It could be seen that the shafts were so arranged in relation to the nominal line that the tolerances increased as the deviation increased, and that round about the nominal size, where accuracy was important, the tolerances on both hole and shaft were small.

As Sir Richard Glazebrook had explained in his Thomas Hawksley

Lecture, it had been found possible to express all limits which grew in proportion to the square root of the diameter in terms of two quantities, one which depended on the diameter and a second which depended upon the deviation or variation from the nominal size of the particular limit under consideration. Thus there was a " size factor " " *m* " and a " range " or " limit deviation factor " " *r* ", the actual limit value being proportionate to the product " *mr*." Values of " *m* " had been tabulated, but reference to tables was not always necessary, as " *m* " could be quickly calculated mentally by anyone with a knowledge of the multiplication table.* It would be quite clear from the method that Fig. 5 gave the relative values of all limits irrespective of nominal size, and therefore that that diagram was universally applicable regardless of dimensions. Tables constructed on this plan could be reduced to a very simple form and could be easily extended by regular rule to any size.

The objection that the method introduced four places of decimals into many of the limit values was, in his opinion, of small consequence. That could not be avoided if the same basic system was to be used for both inches and millimetres, and moreover it was maintained that no sound system covering all classes of engineering could be devised which did not carry dimensions to the fourth place in respect of many of the limits, in so far as those applied to the gauges. While it was granted that it was practically impossible to read a micrometer to the fourth place, there would always be a dimension between the limits that could be read when the use of a micrometer was essential.

To exemplify his previous statement that the standards should be put out merely to establish limit lines with broad indications as to the probable effect of fits and that users should make their own selections from the proposed limits, he put forward Fig. 6 illustrating

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* If D = nominal size in inches; " *m* " is such that :—

$$m(m-1) > 20\,\mathrm{D} \geqq (m-1)\,(m-2).$$

Thus if $\mathrm{D} = 2\frac{1}{2}$; $20\,\mathrm{D} = 50$ and $m = 8$, because

$$8 \times 7 > 50 > 7 \times 6.$$

the particular selections made by Messrs. Aveling and Porter for the application of the B.E.S.A. proposals to 10-ton road roller manufacture. He wished to call special attention to the fact that for the majority of the work the hole limits used were the Y limits, having a tolerance equal to double the proposed normal hole tolerance referred to in the Thomas Hawksley Lecture, and that a large proportion of the shafts were to Q limits. Pairing a " Q " shaft with a Y hole for a YQ fit was found to give better results than were actually being obtained on finished products without limit gauges in the case of many non-rotative fits. Further, in the case of running fits the clearances required were so large that T shafts occurred more frequently than R shafts, which in the ordinary way would give a good running fit.

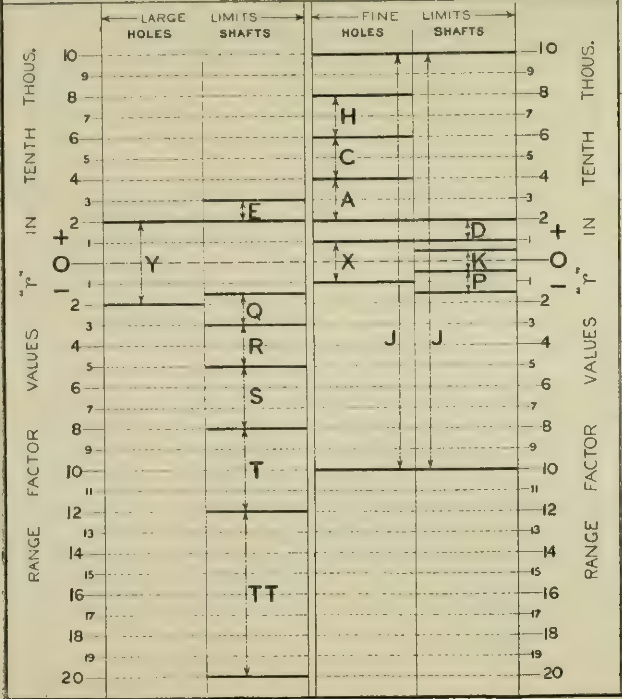
He also pointed out that, whereas taken as a whole the system installed was described as a bilateral system, it was found necessary in certain cases to use the U hole. That was evidence that, despite the raging controversy as to bilateral and unilateral holes, both were necessary in any general system. He mentioned that a complete set of gauges to the limits shown in Fig. 6 had been in successful operation at the works of Messrs. Aveling and Porter for over a year. This was proof of the suitability of these limits for one class of manufacture on the bilateral basis. Approval of the proposals when applied on the unilateral basis had been obtained from the Metropolitan Electric Vickers Co., who had thoroughly investigated the proposals, with the result that that Company was ready at once to install the unilateral scheme immediately the limits were officially accepted as standard. Although at that works the system installed would be on the unilateral basis, there would nevertheless be many cases where bilateral holes would enter the scheme.

The question that had raised so much controversy was whether the bilateral or the unilateral should be adopted as standard. Although personally responsible for the suggested compromise by which both systems could be put forward with a common shaft series, he had always been of the opinion that, taking all things into account, the balance of the advantages was in favour of the bilateral scheme. In view, therefore, of the recent resolution of the

Fig. 6.

PARTICULARS OF ACTUAL SELECTIONS FROM PROPOSED STANDARD LIMITS MADE BY AVELING & PORTER LTD., & APPLIED BY THEM TO GAUGES FOR THEIR WELL KNOWN 10 TON ROAD ROLLERS.

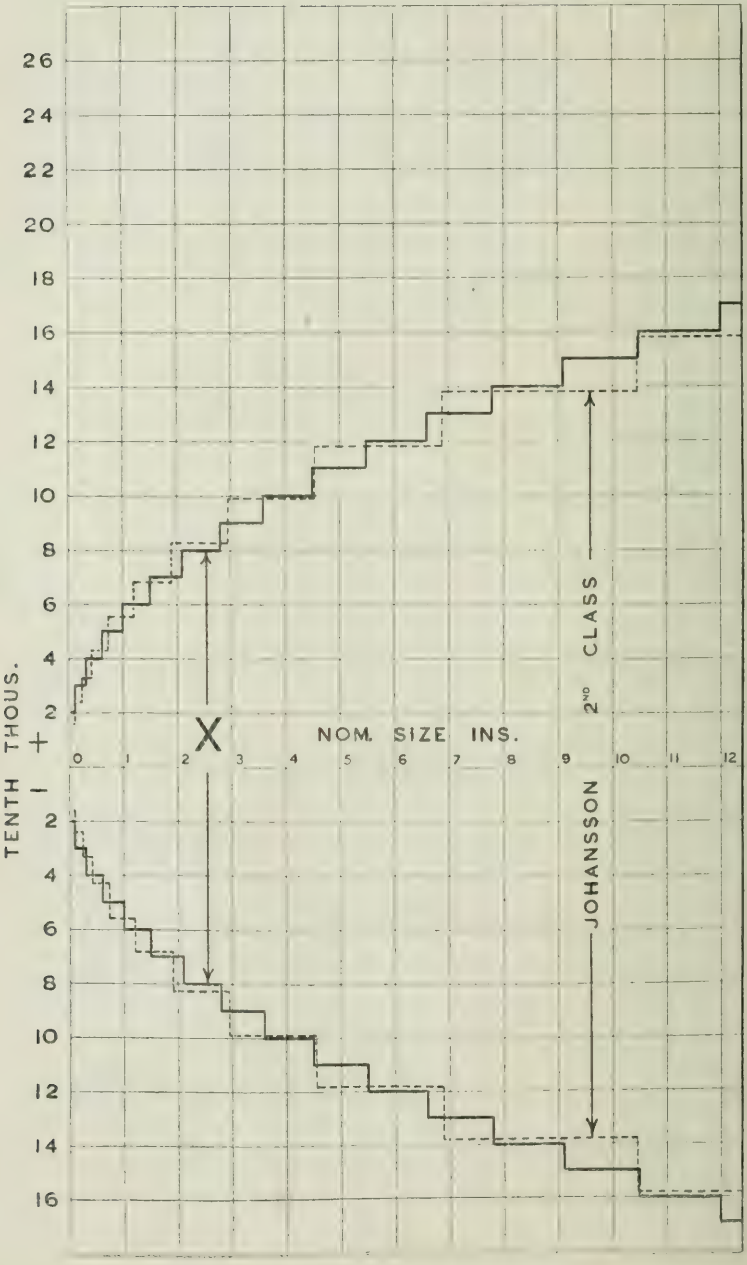
LIMIT DEVIATION FACTORS SELECTED FOR USE BY AVELING & PORTER LTD.



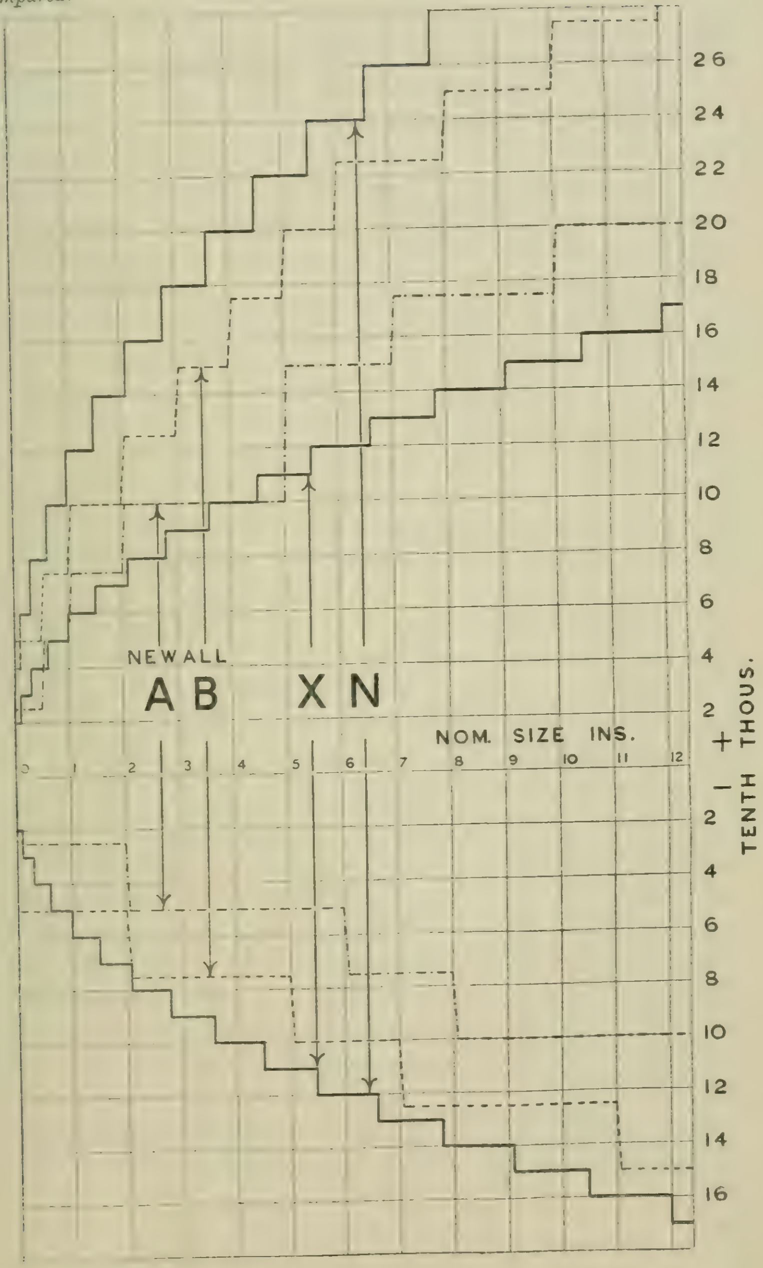
FREQUENCY OF DIFFERENT SELECTIONS.

	GAUGES FOR HOLES LIMIT CLASSES.	No. OF TIMES USED.		GAUGES FOR SHAFTS LIMIT CLASSES.	No. OF TIMES USED.
OVERSIZE	H	1	STANDARD	E	4
	C	1		D	1
	A	2		K	12
SIZE	X BILATERAL	17		P	2
	Y Do.	97		Q	24
SEMI-SPECS.	$\overline{YO}=U$	7		R	11
	$\overline{CA}$	6		S	7
	$\overline{OQ}$	1		T	13
	$\overline{JO}$	3		TT	4
	$\overline{CO}$	1		J	2
			SEMI-SPECS.	$\overline{OX}=L$	1
				$\overline{YO}=U$	7
				$\overline{QR}$	3
				$\overline{RS}$	2
				$\overline{OR}$	6
				$\overline{OY}$	2
				$\overline{OJ}$	1

FIG. 7.—*Hole Limits*



Compared.


NEWALL
A B
X N
NOM. SIZE INS.
0
1
2
3
4
5
6
7
8
9
10
11
12
26
24
22
20
18
16
14
12
10
8
6
4
2
+
−
2
4
6
8
10
12
14
16
TENTH THOUS.

majority on the Limit Gauges Panel, he welcomed the present opportunity to advance a few arguments in support of his view that standards for bilateral users should be included.

He stated that two things could happen in making holes controlled by unilateral plug limit gauges. Either the workman would keep to the " go " size in his endeavour to make a standard size hole, and would thus not take due advantage of the tolerance, or, if he did use the full tolerance, his hole would be twice as far from the standard size as it would have been if controlled by a gauge with a minus " go " size having its tolerance straddling the zero line by an equal amount on each side. Thus unilateral limits would make for greater labour cost than necessary, and would tend towards undue wear of plug gauges.

Reference was made to comparisons shown on Fig. 7, where it was seen that the actual tolerances proposed for the X hole agreed very closely with those adopted by Johansson, though the latter's values did not grow with capacity for extension to large sizes in accordance with any regular law like that on which the Committee's proposals were based.

Turning now to the Newall limits, it would be seen that the proposed N hole lay within limits for the most part just outside the existing Newall " B " hole limits, so that work made to the Newall " B " limits would be acceptable when N limits were specified. Then again, with regard to the Newall " A " hole and the proposed X hole limits, it would be seen that for the most part the Newall " A " limits, both high and low, were slightly plus as compared with the proposed X limits, and that on the high side the maximum difference was of the order of $\frac{2}{10000}$ and that only in the case of gauges over 5-inches nominal size. While the Newall "A" " go " size, was slightly greater than the X " go " size, wear or deliberate lapping would soon reduce the gauge to the X limits. It was safe to say that, except in the case of very special fits, it would be practically possible to utilize the proposed X limits immediately in substitution for the Newall " A " limits.

The two existing systems of limit gauges in use in this country were the Newall and the Johansson, chiefly the Newall, and apart from other considerations it would seem to be a mistake to ignore the grip the Newall system had upon the country, in the establishment of new standards to which existing Newall gauges could not be made to conform. That would be the condition that would arise if the unilateral scheme alone were made standard, for the simple reason that, while it was possible to reduce the size of a plug gauge, it was not economically possible to increase it by a small amount. It had been stated that exponents of the Newall system were defeating their own arguments by supporting a system that introduced any departure whatever from Newall. For many years past the wants and limitations of the Newall system had been recognized, and he believed that there would be little difficulty in persuading the many users of the Newall system to change over gradually to the proposed improved bilateral scheme. To expect, however, that the many thousands of Newall hole gauges throughout the country should be scrapped was expecting too much, and he felt certain that, if the unilateral scheme alone were put forward, present followers of Newall would ignore the work of the Association altogether. Then again, for all firms with established practice the great expense and risk of having to alter drawings, to keep two sets of records and two standards of tools and gauges, to say nothing of two series of spares, during a long transition period, would be altogether prohibitive.

Turning to another commerical aspect of the question, the value of solid reamers in the various tool rooms throughout the country must exceed many tens of thousands of pounds, and at a time when economy should be encouraged, it would surely be unwise to ask that those should be scrapped immediately they began to cut a hole a fraction below the nominal size. It was true that if it were possible to arrange that reamers should be issued by their makers with a starting size well above the nominal, so as to take full advantage of the unilateral tolerance, the reamer effect on the problem would be negligible in so far as the future was concerned, but surely it was not necessary to change the whole reamer practice merely because a new system of limits was being introduced. The same reasoning applied, though perhaps to a less extent, in the matter of broaches and mandrels.

Another argument in support of the bilateral scheme was that it made for simplicity in arranging a scheme of limits to suit different grades or qualities of workmanship. This was explained by reference to Fig. 6 (page 493), where it was pointed out that the difference between the maximum P shaft and the minimum X hole was equal to the difference between the maximum Q shaft and the minimum Y hole, so that for coarse work the tightest fit that could be obtained with a YQ fit would be no tighter than the tightest fit with an XP fit, while the maximum clearance of the YQ fit would be exactly twice that with the XP fit. Thus the YQ fit could be used for many non-rotative fits in coarse work, whereas for such fits the XP combination would be necessary for finer work. This result was possible because when the hole limits straddled the zero line, the low limit receded from that line as the grade of work became coarser, and in so doing came into the neighbourhood of coarser shafts with which it should be paired to maintain the same average grade or quality for both holes and shafts. This device was not possible with the unilateral scheme, because all holes had their common low limit on the nominal line, and in consequence the grading of shafts to suit the unilateral basis was not so satisfactory as for the bilateral basis.

The final argument in favour of the provision in the standards for bilateral users was that by making that provision the B.E.S.A. would go a long way towards ensuring the adoption and success of its recommendations. It should be recognized that whichever system might be thought to possess a preponderance of advantages, resort would have to be made to the other on occasions. He therefore suggested that the whole controversy should be dropped entirely and the compromise adopted at once, so that the bar to progress would be removed with the certain knowledge that there would be agreement in regard to a very large proportion of the limits, notation, and gauges in use throughout the country.

Before concluding, he wished to make a few remarks in reference to transition and interference fits. It had been suggested by some that transition, and even so-called push fits, should be altogether omitted from the tables. He did not agree with this suggestion and mentioned that the XK fit, which equalled the UC fit, styled "medium keying"—midway in the so-called transition group, was practically identical with the so-called keying or "festsitzen" fit of the Loewe system, which had been in use for about twenty years. No difficulty in ordinary work would be encountered with that fit, particularly when limit gauges, properly applied, were used to control the hole and shaft dimensions. The present opportunity should be taken to state that too much stress could not be laid on the importance of insisting that actual limit gauges should be used by operators in producing work to the specified limits. It was too late when the work reached the inspection room. It was true that for many shaft dimensions the use of micrometers was desirable, but for best results they should always be used in conjunction with a controlling limit gauge. Placing limit values on the drawings and leaving it at that was insufficient where maximum economy was required, and never ensured that certainty as to interchangeability possible with limit gauges properly controlled as to size.

Returning to the question of interference fits, it would appear that those to a large extent must be treated on their merits, although provision should be made in the tables for certain oversize shafts, from which selections could be made to suit requirements. Records of press fits indicated that in the majority of cases the obstruction might become excessive for large sizes if made to increase directly as the diameter.*

He could only hope that the result of the Meeting would be to crystallize ideas, so that at long last a national system of limit gauging might be inexpensively introduced, with permanent benefit to the whole engineering industry.

Dr. P. G. AGNEW (Secretary of the American Engineering Standards Committee) gave two pieces of information with regard to the American work which, he thought, might be of interest to the members. First, it was now practically the universal custom in

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* Journal, Am. Soc. M.E., 1913, vol. 35, page 819.

America to use the hole as the basis. Second, there was a very strong tendency towards the unilateral system, or as Colonel Peck, the Chairman of their Sectional Committee, had put it, towards making the main dimension on the drawing represent maximum metal. He thanked the Institution very much for the opportunity of joining in the discussion.

Mr. A. E. **Berriman**, O.B.E., said the one real fact in the present situation was that the British Engineering Standards Association's Committee was agreed to recommend that the hole should be the nominal size. It had been widely assumed that the next question to be answered was whether the tolerance on the hole should be unilateral or bilateral, but he suggested that the next step ought to be to standardize a system of shafts. He was of opinion that a rational basis for such a system existed, and that Mr. Hedley Thomson's development of it was reasonable enough to form the basis of a good standard. The true significance of the unilateral or bilateral tolerance on the hole was much more readily appreciated in the light of an existing system of shafts, and he doubted whether the difference was sufficient actually to declass a fit in the majority of practical cases. The arguments in favour of both systems had been logical and lengthy, but they had served only to disclose the hypothetical character of their premises. Personally, he inclined to the logic of the unilaterals, but he respected his own reason sufficiently to admit that his bilateral friends had a very strong case. A vote on this question might yield a majority, but would not carry conviction, and he thought the interests of engineering were likely to be served better by legislating for both parties and, if necessary, recording a majority recommendation in favour of one, rather than by making one system only the exclusive standard and thereby alienating the support of the opposition.

Under Mr. Hedley Thomson's system, a 2-inch " Q " shaft had the same absolute dimensions everywhere, and the question whether its combination with a 2-inch " X " hole produced a significantly different fit to its combination with a 2-inch " U " hole was very much a matter of experience on the particular job. In his opinion the naming of different classes of fits had interfered somewhat too much in the question of limits. Paraphrasing an old adage, he was almost inclined to say: If the B.E.S.A. takes care of the limits, the fits will take care of themselves.

Mr. Max R. Lawrence said he was strongly in favour of the unilateral system because he had found that one of the chief difficulties in dealing with tolerances was deciding and recording on drawings of fits which had to depart from standard, and where a number of pieces had to be assembled and an over-all fit attained. With the bilateral system, the amount when ascertained had to be halved and half the amount added to or subtracted from the name dimension. This made clear thinking more difficult. With the unilateral method the size of the shaft of the whole could be fixed at the finest possible clearance, and then the tolerance figured in the direction of wear, that is, plus for a hole and minus for the shaft.

In figuring these tolerances, due regard must be taken of the method of manufacture and value of the pieces. In some instances all or nearly all the tolerance should be given to the most difficult or expensive part. Take, for example, an automobile piston and cylinder fit. It was ascertained that the minimum clearance was $2\frac{1}{2}$ and maximum $3\frac{1}{2}$ thousandths. Both parts were finished by grinding, so $+ 0 \cdot 001$ was given to the cylinder and $- 0 \cdot 0005$ to the piston. With the bilateral system, this would be very cumbersome to express, and, further, when this fit came to be measured, say with a feeler gauge in the shop, quite a large amount of arithmetic had to be done before the information was got from the drawing.

Mr. C. le Maistre, C.B.E. (Secretary, British Engineering Standards Association), said he appreciated very much the opportunity of being permitted to join in the discussion, but as Secretary of the Association he could naturally express no opinion. A number of points, it seemed to him, of great importance had not so far been dealt with in the course of the discussion, but probably that was because they did not enter quite so much into the technical side of the question as the human. Standardization was about

15 per cent technical, the rest was human. It was comparatively easy to set up a standard, but enormously difficult to get it adopted. The sole object of the Association was to assist industry to unify its requirements, and industrial standardization could only be arrived at as a matter of compromise, and was not a question of vote. Indeed, if it was put to the vote and carried by a small majority, the Association could probably adopt only one course, namely, to wait until the majority was larger.

A number of points in connexion with how the question was to be approached were of importance. Was it to be approached from the point of view of national interest with a view of trying to attain some measure of national interchangeability? Were they to endeavour to unify the needs of a certain number of firms at present using some system of limit gauging, or to consider the far larger number who used none? If the question was to be approached from the point of view of the work, was it not necessary in order to unify the needs of the industry, as had been done in many other cases, to inquire from the industry what its present practice was with regard to tolerances for the particular work they were engaged upon? The interest in the subject was growing at a tremendous rate, and he felt that, before the Association could make further progress, it would be advisable again to consult the industry. The question as to the form the report should take had been very ably advocated by Mr. Taylor, with, he was perfectly sure, the very kindest motives; moreover, he did not think more self-sacrificing labour or keener interest had been taken in any work of the Association than in that connected with this question of limits.

Major P. Bishop, A.I.D., said that he favoured the unilateral system on account of its convenient application to a system of recording the limits in which he was interested. Before dealing with that subject, however, he would like to have an explanation from Sir Richard Glazebrook as to the definition of the system in the case of force and push-fits where interference occurred. He imagined that in such cases a bilateral limit was necessary for one of the elements, either male or female. The system to which he referred was that adopted by the British Engineering Standards Association (Report No. 84) in connexion with screw-threads, and was known as the "Grade and Play" system. He could not see why that system could not be applied to ordinary cylindrical diameters with advantage as well as to the complicated diameters of screw-threads which involved several elements, all of which had some independent relation to each other. The use of curves and voluminous tables for recording limits on various diameters for certain fits was very frightening to those in the workshops and drawing offices, and in no case could anyone memorize or determine quickly the particular tolerances or limits required. A few years' experience of the "Grade and Play" system had been obtained, and throughout the country the limits of screw-threads could now be memorized without any reference to a table at all. The system was also specially applicable to shadow measuring, which had certain advantages for precision and repetition work.

Sir Richard Glazebrook, in his opening remarks, had stated that there was a tendency to define tolerances for work only, no mention being made of allowances. He did not gather quite what was meant by that, because if the allowance were missed out, the tolerances required for the gauges would have to be robbed from the work tolerance, which, although quite right for workshop gauges, could not be done in the case of inspection gauges for legal reasons.

With regard to the subject of steps and ranges, for the reason he had already mentioned he would prefer to see the unit step one-thousandth instead of half-a-thousandth with ranges in even inches, but admitted this was a biased opinion from the point of view to which he had already referred.

Mr. Richard W. Allen, C.B.E. (Member of Council), said he thought the discussion on the question of the use of the unilateral versus the bilateral system had been a most interesting one. Most of the speakers had dealt with the question from their own point of view, but he was particularly glad to hear Mr. le Maistre's remarks, because he thought that gentleman had touched the right spot, namely, the human element. Those people who employed limit gauges on either one system or the other would obviously say that whatever system they had adopted was the better of the two ; that was only human nature. Mr. Hedley Thomson had stated that he went to Berlin in 1903 to study the Ludwig Loewe system He (Mr. Allen) also went to Berlin about twenty-two years ago and studied the same system of limit gauging, and so satisfied was he with it that his company adopted their system of bilateral limit gauges, and had used it ever since. Many of the speakers had referred to the objections to it, and one in particular mentioned the question of the drawings. He could assure the members that there was no objection to the system from that point of view. The draughtsman simply put on the drawings whether it was a running fit or hydraulic fit, or any other kind of fit, and, from a practical point of view, the work as turned out by the bilateral system was equal to that turned out by the unilateral or any other system, provided the limits were right.

He agreed with Mr. le Maistre that the question should never be put to the vote ; in his opinion it would be dividing the manufacturers of the country, and would be quite a wrong thing to do. He viewed the question very largely from the point of view put before engineers some years ago as to whether they should change from the Whitworth system to the metric. That evoked tremendous discussion in the country, and the same state of affairs would occur if large firms, which had adopted the bilateral system, and had machinery made by them all over the world, were asked to change to the unilateral system. They could not possibly afford to change. Spare parts and such like had been produced, and they could not run the risk of using another set of gauges. No one company was big enough to say that it would change over, when it bore in mind the enormous capital outlay involved and the consequent confusion arising in installing new limit gauges. There was a great number of sizes, from 1 inch up to, in many works, 3 feet or 4 feet, varying by $\frac{1}{8}$ inch, and each size comprising no less than six gauges. From that point of view he was particularly glad to hear Mr. le Maistre's remarks, because he was very nervous when he saw so many supporters of the unilateral system coming forward. He viewed the question in a very different light from the recommendation of the British Engineering Standards Committee in regard to keyways, which simply involved the alteration of the keyways, but to change one's whole system of dimensions was like reconstructing the whole of the business. He desired, however, to say in conclusion that if his firm had not adopted the bilateral system, they would probably have adopted the unilateral system.

Mr. T. W. Cooper said he was exceedingly pleased, like the last speaker, that the human element had been brought into the question. The Hoffmann Manufacturing Co., which he represented, adopted originally the bilateral system for the making of bearings. They did so for the reason that they felt it was necessary, in manufacturing a hole or a diameter, to get as near to it as possible, and they thought they could do that better by disposing the tolerances on either side of the nominal dimension. The members could easily imagine the number of gauges that his firm had at the present moment, not only in the course of construction, but actually in use, and what it would mean for them to change over from the bilateral to the unilateral system. He quite appreciated, from the other point of view, the advantage of having the tolerances opposed on either side of the nominal when it came to reckoning up the amount of clearance it should have, but apart from that he saw very little in it.

Major Andrew A. Ross, O.B.E., said that at an early stage of the War he was instructed, as the representative of a Government Department, to visit a large number of manufacturers with the object of seeing if it was possible to ensure standardized production of interchangeable aircraft engines and spares. He was told, if possible, to try and encourage contractors to adopt the Engineering Standards Committee's system, but, after visiting many contractors who were manufacturing engines, or parts of engines and accessories, he found, generally speaking, that practically none of them were using the Engineering Standards Committee's limit system.

The system greatly in favour was a bilateral one, and on inquiring why the manufacturers—many of whom were Government contractors of long standing—were not using the Engineering Standards system, he was told that this system was not applicable to modern engineering work, but only to the heavy or marine type practice, and was not at all suitable for the class of work where grinding machines replaced the older methods of manufacture. The old Engineering Standards system only dealt with running fits, and did not deal with the most important fits which were now known as "transition" fits, and for interchangeable work with large quantity production some new system was therefore necessary. The bilateral system which was mostly favoured was that known as the Newall system, but that system had many defects in regard to transition fits. Nearly every contractor in the course of time had gradually altered the Newall system by modifying the transition fits to suit his own particular class of work or method of working.

As a result of these inquiries he became a rabid bilateralist, but as time went on, however, he had to deal with other contractors who were turning out excellent interchangeable work on the unilateral system. The Government Departments concerned were largely in the hands of the designer with regard to what system ought to be used on the standard drawings. As far as possible they were using the bilateral system on their own drawings, but they had to adopt, in some cases, the unilateral system, so that before the end of hostilities these Departments had a very wide experience of the result of manufacturers using both systems. After considering both sides, he was very much in agreement with Mr. Berriman that it was six of one and half-a-dozen of the other in favour of which particular system should be adopted; there was very little to choose between them from the results in producing interchangeable manufacture.

In discussing, during his visits to various manufacturers, the possibility of adopting a standard system, he was informed that it had been impossible to adopt the old Engineering Standards system, owing to commercial considerations, affecting particularly the gauges and methods which had been installed in the works; so that ten or fifteen years might elapse before a system became standard, even if it could be generally adopted. If it could not be generally adopted it would be ignored. If it was desired, therefore, to give some lead to the industry, the recommendations must be such that they could be generally adopted and with a standard system of limits for interchangeable work the main object of standardization must be clearly visualized —that is, a user desiring to order a particular article to fit in with his own production or equipment should know to within what dimensional limits he might expect that part to be delivered. If, without asking for detailed drawings, an arrangement could be instituted so that all parts were manufactured to " such " and " such " a system, the manufacturer would be quite satisfied. In the past, contractors and the Government were satisfied that engine parts should be manufactured to the Newall system. As it was impossible to get the manufacturers of the country to agree to one particular system, because of the personal elements that had already been mentioned by other speakers, it seemed desirable to try and arrive at a compromise such as had been put forward so ably by Mr. Hedley Thomson; and provided both systems—namely, one standard system of shafts with two systems of holes—were clearly known to the whole of the industry, it seemed to him that the immediate requirements of standardization could be met.

Colonel R. E. B. CROMPTON, C.B., R.E. (T.), said that he had been dealing with the question of limit gauges for seventeen years, and he hoped he would see some settlement of the question before he died. Personally he thought it would be wrong to take a vote on the subject ; he thought it would be far better if a compromise could be arranged, and efforts were now being made in that direction. He thought that a workable compromise could be brought about, and he was sure the point of view Mr. le Maistre had put forward was the correct one. It was necessary to consider the trade, and to feel their way if the members wanted to see some standardization of limits brought about.

Mr. HERBERT CARPENTER said it seemed to him that the British Engineering Standards Association were a little late in the recommendations they had made. In his opinion they ought either to have brought up the subject early in the War, when so many different firms were making the same interchangeable parts, or to have spent more time in standardizing work that was to be interchangeable. It was of little use having a standard system of limits until firms made more parts interchangeable with those on similar products made by other manufacturers. The B.E.S.A. had standardized such things as steel joists, gas-pipes, and bolts and nuts, but few people worked to fine limits on those articles, except the latter, and they were more or less interchangeable before limits were seriously considered. One point in favour of the bilateral method that had not been mentioned on the practical side, was the wear and tear of reamers and broaches. It was not the practice, even now, to grind small holes, and reamers did not wear large.

Sir Richard Glazebrook, in reply, said that the position was that if they were starting afresh there could be no doubt that they would start on the unilateral system. When an endeavour was being made to standardize, it was desirable to take quite a wide outlook and to see that the system decided upon would be adopted, not merely in this country, but fairly generally outside it. Dr. Agnew had stated that it was almost certain the unilateral system would be adopted in America. The members knew that the unilateral system had been adopted on the Continent, and this country already used the unilateral system in connexion with screw-threads. That would have to be altered if the bilateral system was definitely adopted for holes. That being the case, he hoped that it would be possible to arrange in some way that for new work the unilateral system should be worked to, leaving it open to those who were wedded to the bilateral system and using it to continue to use it for all their old work, and possibly for some time for general production. But their gauges wore out in time; their standards needed renewal, and as that happened he hoped it might be possible for them to change over to the unilateral system. He thought the arrangements which had been made in Germany on the subject were very much to be commended. The members had heard how Messrs. Loewe and Co. were the fathers in Germany of the bilateral system, and how their system had been used in this country to a large extent ; it had formed the basis of what Mr. Allen and other speakers had said. The position of the Johannson gauges in Sweden was also known. When the members heard that firms abroad, who were so deeply committed to the bilateral system as these gentlemen were in the past, had all come together and agreed that it was in the interests of manufacturers in Germany that they should do their best to change and adopt the unilateral system, he hoped that, in time at any rate, the same view would be accepted in this country. It might then be possible, ultimately, to have a standard unilateral system. For the present he realized that it was necessary to have some kind of compromise, and that if the series of shafts which had been put before the Committee by Mr. Hedley Thomson were adopted, it was quite possible to use them with a standard unilateral hole, and at the same time to get good quality interchangeable work with the bilateral hole which Mr. Hedley Thomson had been supporting. By the adoption for a time of some such system he hoped the difficulties might be overcome, with the ultimate object of settling down to the unilateral system.

Discussion in Leeds on Monday, 2nd May 1921.

The CHAIRMAN (Lt.-Col. E. KITSON CLARK, Member of Council) said it was desirable that the important question of Limit Gauging should be standardized on sound practical lines, first in this country and then internationally. Having been present at the discussion which took place in London recently, he considered that they were very fortunate in persuading Mr. Hedley Thomson, a Member of the British Standards Committee on Limit Gauges, who had devoted a lifetime to the special study of this subject, to open the discussion on behalf of Sir Richard Glazebrook.

Mr. **Hedley J Thomson**, with the assistance of diagrams and lantern slides, introduced the subject on behalf of Sir Richard Glazebrook, covering in a most able and detailed manner the whole of the ground already dealt with at the London Meeting. (*See* page 486.)

Mr. **R. Crosby** agreed with Mr. Thomson that it was necessary to adopt a general system of limit gauging, and the most effective method to his mind was the bilateral system. Under this system, one ensured the hole being as near the nominal size as possible. As an illustration, he might mention a system brought to his notice some years ago. The firm in question had a limit gauge system running in the shops with limits as generous as the work allowed. All the work was passed into an Inspection Dept. which was equipped with two additional limits, one higher than the standard and one lower. Work which passed standard limits was transferred into the stores, with a white label ; that which failed to pass the standard limits, but which passed the alternative set of lower limits, went into the stores under a red label. On the other hand, work which failed to pass the standard limits, but satisfactorily passed the alternative higher limits, went into the stores under a green ticket. On assembly or erection, the foreman receiving an order for a number of parts to be assembled would draw from the stores complete sets of parts of white, green, or red work, according to the quantity required. It was then noted in the office which grade of limits the customer had been supplied with, so that the question of replacements came under proper control. This system was easily worked and eliminated scrap and adjusting on the bench, and was equally suitable for large or small production. He thought that Mr. Thomson had ably shown that limit gauging on the basis laid before the meeting was capable of being adopted to suit all classes of work.

Mr. Francis J. Bostock said that to confine limit gauging to repetition work, as appeared to have been done in the past, was, he thought, a great mistake. Whilst it was true that it could be readily applied to standard production, the system to be satisfactory, should be of universal application. Modern methods of high class production depended upon a separate drawing being made of each individual piece, even if there were only one or two required. Furthermore, the various components for the complete unit were machined in different departments and were not made to suit each other in the ordinary sense of the term, but were machined independently and not tried together until they reached the assembling stage. This therefore meant that a proper system of limits and tolerances thereon must be worked to, but unlike repetition work, the quantity required was so small as to preclude the making of special limit gauges except in the case of standard dimensions, say, up to 3 inches in diameter.

Fixed limit gauges were admirably suitable for repetition work. The grinder, for example, after the first piece had been finished, set a stop on his machine so as to determine automatically the size of the piece being ground, and after reaching this stop he applied his limit gauge (set to Johannson gauges) in order to get within the tolerances given. Not so, however, with single pieces; the workman nowadays did not like to be in a position of having finished his piece before he could measure it. Scientifically speaking, there was no difference between the unilateral and the bilateral systems, and, whichever were adopted, it must be the most suitable one for the workman. Generally speaking, there was a tendency among all workmen to work to the " go " limit rather than the " no go " limit, so that even by aiming at the nominal size probably the bore would be one or two-tenths of a thousand small which, for the bilateral system, would be quite in order.

He (the speaker) found from his experience that the Newall system, whilst very good in its way and an excellent basis for a start, was unfortunately deficient in many respects. For ordinary high class work one very seldom required to work to the " A " limit for standard holes. Generally the " B " one was adopted, but he was inclined to think that a limit with greater tolerances could be satisfactorily used specially in conjunction with running fits. Except for slow speed work the " Y " and " Z " limits were seldom used. Generally for medium speeds the " X " limits were satisfactory, but for speeds of about 1,000 r. p. m. they were insufficient, and he had found the range of " XX " (that is, twice the limit of " X ") to be very satisfactory in service. He thought that two intermediate fits were required to complete the Newall system. The first should be a " Light Tapping " fit, such as was required for a journal bearing on its shaft when not secured in position by a lock-nut. A further fit, which might be called a " key " fit, was also required. There was too much of a jump between the " P " and the " D " of the Newall system, and he had found it necessary to introduce a " medium drive " fit for shafts and wheels which had to be keyed together.

He suggested that a full series of fits be plotted out on the lines suggested right up to 20 inches in diameter. At the same time he realized that whilst it would be satisfactory for perhaps 90 per cent of the work, there would still be special cases to be considered on their merits. For example, none of the running fits above mentioned would be suitable for very high speed work wherein the bearings were fed by oil under pressure and had perhaps a rubbing speed of 8,000 to 10,000 feet per minute ; in such cases the limits required were about six times that of class " X." By the aid of the range factor, any works would, however, be able to make their own special limits for their individual requirements.

Major F. L. WATSON, in moving a very hearty vote of thanks to Mr. Hedley Thomson for attending the Leeds Branch Meeting to open the discussion, said that Mr. Thomson's remarks as well as his diagrams had made very clear the various points dealt with by Sir Richard Glazebrook. In view of the importance of the pending decision of the British Engineering Standards Association, he felt that it was the duty of members to express a definite opinion as to the unilaterial or bilateral system of assigning the tolerances. He felt that the necessity of adopting the standard hole diameter with varying shaft diameters for different classes of work was definitely justified.

The question of the assignment of tolerances above or below the nominal dimension was, however, on a different footing. It was not a question to be settled by scientific reasoning but was entirely a practical question. The tendency in manufacture would always be for the dimension of the part actually produced, to approach a position between the maximum and minimum allowed. On the bilateral system the actual result would, therefore, approach the nominal size. The mean between the high and low limits would be approximately the same for all classes of work, so that whether a large tolerance or a small tolerance were in use, the actual or normal dimension obtained in practice would approximate to the same figure. On the unilateral system, on the contrary, the actual or normal size obtained, tending as in the other case to a position between the two limits, would in the case of a hole diameter be larger and in the case of a shaft diameter be smaller with a large tolerance than with a small tolerance.

The governing factor in the provision of standard holes (except of large sizes), lay in the provision of twist drills and reamers of the required accuracy. Unless different sets of twist drills and reamers were to be used for the different limits of accuracy, the result would be that, whereas with fine limits the permissible error might be equal on both sides of the normal, with large tolerances, the difference allowable would be mainly on one side, and thus facility of manufacture provided by the larger tolerances would be vitiated. In his opinion the balance of advantage lay with the bilateral system. He did not agree with Sir Richard Glazebrook's contention that in looking forward we should have regard to the interest of the many firms who did not now use limit gauging, but would do so if a standard system were generally recognized, rather than to the convenience of those who had adopted a system excellent in many respects, but, in Sir Richard's opinion, not quite the best. If this principle were adopted by the Association, it would have the unfortunate effect of discouraging enterprise, because there was an obvious disadvantage in adopting improved methods in their early stages, if one was to expect that, having spent large sums of money on a system which suited one's own business, the whole was to be scrapped through the adoption by the B.E.S.A. of a modified system, devised chiefly with regard to the interests of those who had adopted the attitude of "wait and see."

He did not agree with Mr. Bostock's opinion that in shops doing non-repetition work it was desirable to adopt a system of limits, but not a system of limit gauges. The suggestion that limits should be shown on the drawing and the work carried out by means of micrometers placed in the hands of the individual worker was not in his opinion practicable. Several workmen using different micrometers in different departments, for example, the borer using a micrometer on the hole and the turner independently using another micrometer on the shaft would not ensure a satisfactory result. For work of a non-repetition character such as the building of individual machines or engines, the advantages of using fixed limit gauges were the same in kind and only different in degree from the advantages of using them on repetition work. It was essential to the working of such a system that one department under the charge of one person, for example, the tool-room, should be responsible for the preparation, checking, adjustment and issue of all gauges. Whilst for non-repetition work there was an important saving in the use of gauges which were capable of adjustment, such adjustment should always be carried out by the tool-room, and the gauge as issued to the workman should be, for the time being, a fixed gauge.

Mr. GUY L. MURRAY said that with regard to the question of hole or shaft basis, there were many arguments that could be put forward in favour of the hole basis, but only a few that could be claimed with respect to the shaft basis. The main arguments in favour of the hole basis were briefly: (*a*) simplicity of manufacture; (*b*) less plant and equipment required; (*c*) economy in gauges required; and (*d*) the fact that so few firms were able to adopt the B.E.S.A. Report No. 27, which was on the shaft basis, proved that the latter stood condemned.

The arguments in favour of shaft basis were (*a*) In the case of main line shaft and millwright work, where the shafts were reeled to size, the only practical solution was to make allowance on the size of the hole and use the shaft basis; and (*b*) where the class of work was such that the hole had to be case-hardened or heat treated, thus necessitating finished grinding of the hole, it was sometimes more economical to vary the diameter of the hole in accordance with the class of fit. This often applied to locomotive practice. Exceptions would always have to be made in favour of the shaft basis in cases of this kind.

With regard to the unilateral versus the bilateral system, there were arguments to be used on both sides, but it would appear that none of them were of any real practical importance, and it seemed to him the main fact to bear in mind was that the most commonly used existing systems, namely, the Newall and Johansson, were both on the bilateral system. It seemed rather unfair to ask firms who were equipped with these systems to scrap all their gauges and to substitute new ones which might be more academic, but which could not possibly give the user any better practical results than the systems at present in operation. Seeing that the question of revision of the English Standard Specification was at present under consideration, would it not be preferable and a suitable opportunity of bringing it into line with the bilateral system, and so avoid a large amount of unnecessary expense to the manufacturer? He would urge that the firms who have been enterprising enough to adopt limit gauge systems already were certainly entitled to more consideration than they seemed likely to get.

With regard to the systems of limits, and item (*b*)—the quantity to be dealt with—he thought it was important to call attention to the necessity of due consideration being paid to the various coefficients of expansion of the materials that might be employed, and the temperature changes that sometimes took place in the working of the complete machine. For example, limits that might be quite satisfactory for a cold bar shearing machine, would prove disastrous for a machine of the same type which was required to cut continuously red-hot billets.

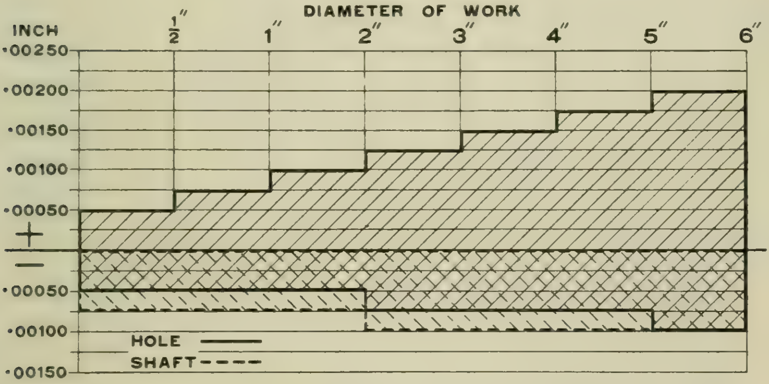
In considering the question of steps and ranges, it might be more desirable that something should be done to make them conform more to the parabolic law, and he would again urge the case of due regard being paid to gauges and systems at present in use.

With regard to the various kinds of fits, he thought we should all be in agreement that limits for running fits should be, and could be, standardized, always excepting special cases. As to transition fits, he wished to emphasize the importance of keying fits. This class of fit was met with in almost every workshop, and probably was the least satisfactory and most expensive from the point of view of lost time, unsatisfactory work, and wasters. He thought that the question of limit gauging for the keying fit should receive every attention, as, from a manufacturer's point of view, it was as important as the running fit.

During the past eighteen months he had spent a fair amount of time considering, adopting, and putting into operation a limit gauge system as applied to heavy machine-tools of great variety and covering a large range of sizes. The most important fact to bear in mind when adopting a system of limit gauging was that the system adopted should be one that would enable the workman to produce his work with greater confidence, with less risk than formerly of producing wasters, and that the gauges supplied to him should be such that economies in time taken per operation might be brought about. From this it naturally followed that the limits adopted should be no finer than was absolutely necessary to ensure the satisfactory running of the machine or article to be manufactured. In his case, he had been particularly interested in establishing standard limits for two kinds of fits, namely, running and keying. The plan adopted in finding out the desirable limits was extremely simple, and consisted in thoroughly examining completed new machines which were running satisfactorily in the shop under test, and from them ascertaining the allowances and tolerances that the shop had previously more or less unconsciously been working to. The figures got from this source were then compared with tables of standard allowances by various makers of limit gauges until the nearest table was found. Further investigations were then made with this table, and they took the form of preparing by the ordinary shop method of manufacture a set of holes and short pieces of shafts to the limits given in the table of standard limits it was proposed to adopt.

In the case of the running fits, care was taken to see that proper provision had been made to allow a satisfactory oil film to be maintained between the shaft and its bearing (the hole). In the case of the keying fits, the limits were necessarily of a much finer nature, and it was important to see that any interference between the shaft and the hole that might arise, was not more than would permit of the shaft being tapped with a light hammer into the hole; further, it was necessary to find out that the maximum possible allowance was not sufficient to interfere with the concentric running of the gear wheel, pulley, etc., that had to be keyed on to the shaft. He had found from experience that these points could be satisfactorily met by adopting a modified form of pushing fit, as given in the Newall Standard of Allowances. This system had now been in use for about 12 months, with satisfactory results. A diagram of this keying fit was shown in Fig. 8. The tool-room should be equipped with satisfactory reference gauges, so that all gauges might be rapidly checked on giving out to the workman, and again when returning to the tool-room.

Fig. 8.—*Keying Fits.*



With regard to the use of gauges by the workmen, he would strongly advocate that, before introducing a limit gauge system into a shop where no system at present existed, instructions and demonstrations be given to the workmen concerned in the proper use and object of the gauges, in order that they might be taught to respect and not abuse them. Especially was it important to point out to the operator that the "go" gauge "should go," and that he is not called upon to make it fit a hole or shaft.

On the question of the care of gauges, he had found that, in order to save calliper limit gauges from unnecessary wear and tear, and to prevent the operator attempting to apply them to the shafts running in the grinding machine, it was advantageous to equip the operator with a set of what he called "approaching disks." These were ground $\frac{2}{1000}$ inch or $\frac{3}{1000}$ inch larger than the high limit of the calliper gauge. The operator set an ordinary pair of callipers to these disks and could apply them to the shaft in the machine when running, and only use the calliper limit gauges when the diameter of the work was within a few thousands of that required. He had found this system very successful, which effected a saving of time taken in the grinding operation, as the machine was not stopped so frequently.

Professor G. F. CHARNOCK seconded the vote of thanks to Mr. Hedley J. Thomson, who, he remarked, had not only opened the discussion, but incidentally had given a masterly and up-to-date exposition of the subject. He could not help thinking that the matter might have been made much clearer and easier to retain in the memory by the introduction of a suitable system of symbolical notation, and, although it was of course essential to preserve the utmost simplicity, he deprecated the idea which had been emphasized rather strongly by several of the speakers at the discussion in London, that a simple algebraical expression should be consigned to the Appendix.

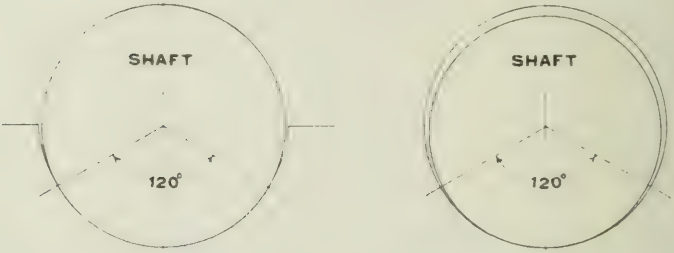
The CHAIRMAN said that a controversy was always attractive, and the division between the bilateral and unilateral schools had caused both scientific and practical aspects to be thoroughly examined. Possibly as both systems were really based on a convention, the shops themselves would now select that which suited them best. He felt that the point at issue might be very briefly and clearly detailed, that a season might be allowed to elapse, and a questionnaire again submitted to those most concerned. But one thing he held to be of great importance was that the letters used to designate the different tolerances of holes and pins in reference to different classes of fits should be made universal—not only in this country, but abroad; and that they should be applicable for both the British and metric systems of measurement. This would appear possible on the reasonable assumption that $\frac{1}{1000}$ inch = 0·025 mm.

Communications.

Mr. J. E. Baty wrote that, without wishing to criticize unduly limit systems evolved many years ago by the B.E.S. Association, Messrs. Newalls and others, which had without doubt served their purpose in the development which had taken place, he thought it was necessary to postulate more carefully the general requirements with regard to limits.

The E.S.C. Report No. 27, 1906, laid down :—" Par. 6. *Qualities of Work.* For general engineering practice, the Committee have laid down three classes of workmanship, namely :—1st class; 2nd class; 3rd class. They do not stipulate the employment of any one of the above classes in any particular case, but recommend that one of the three classes be worked to in whole, or in part, as may best meet requirements." The point the writer wished to emphasize was that the various grades were for different classes of workmanship and not for parts to work under different conditions, say in hot or cold positions, Another point in this Report and in some other systems, was that, as shown in the Proceedings, 1920, Fig. 4 (page 1085), the maximum limit of the first-class fits was the minimum of the second-class fits, and so on with those of the third grade. This brought one to the question: What constituted a good running fit? Those who had had practical experience in engine and such like work knew that, in a split bearing, if there was any tendency to fit against the shaft on the diameter where the split occurred that the bearing would heat. Bearings were therefore cleared away slightly, as shown exaggerated in the left-hand sketch of Fig. 9, generally leaving an included angle of bearing surface between 90° and 120°, depending upon the class of work.

FIG. 9.



Bottom Half of Split Bearing. Solid Bearing.

Supposing, instead of a split bearing, one had a solid bearing. If any limit was allowed between a shaft and a hole, then under running conditions the shaft would not take up a central position in the hole but would lie to the side on which the thrust or pull forced it. Referring to the right-hand sketch of Fig. 9, which showed in an exaggerated manner a shaft thrust over to one side of a solid bearing, the clearance gradually increased until at the point opposite contact one got nearly the limit of the hole plus limit of shaft. The shaft would be in a cradle of oil in various states of compression and, so far as it was possible to calculate or imagine what the exact arc of contact was for a hole and shaft to fine limits, it appeared to the writer to be analogous to the split bearing already discussed above. This would seem to point to the necessity of a practical investigation as to what constituted the best arc of contact. He thought this arc determined good or bad running and it bore no relation to a $\sqrt{D}$ law.

A point of interest here was the old workshop method, that is, before the time of limit-gauges, of making a hole a running fit to a given shaft. An inside micrometer was set to the exact diameter of the shaft (from an outside micrometer or a pair of outside callipers) and the hole was then bored so that if the micrometer was pivoted from one end, the other end had a lateral play in the hole of $\frac{3}{4}$ inch for each foot diameter of hole, that is, Play $= \frac{3}{4} \times \frac{D}{12}$. This worked satisfactorily and corresponded, in actual limit between shaft and hole, when well done, to the finer classes of tabulated limits.

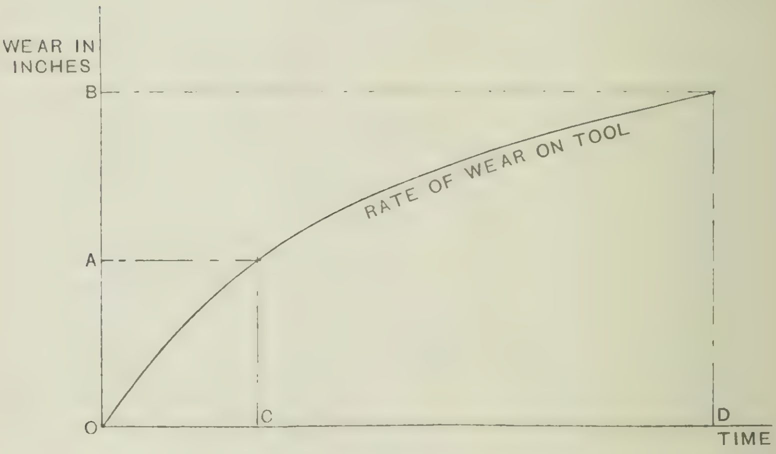
The foregoing paragraphs referred to minimum clearances between shaft and hole, and the next point was that having made at least this allowance the finish of the work was not so important; it might be ground to a finish or turned in the lathe and it would run equally satisfactorily. Hence he did not agree with the second class limits starting where the first class ones finished, but that the second class should overlap the first class and that if a third class was necessary, it should overlap the other two.

Limit gauges were adopted in order that (1) work might be made interchangeable in quantities; and (2) to get an increased output with a less skilled workman than would otherwise be necessary.

Arising out of the second of these reasons, it might be as well to look for a moment at the method of application of the limit system in a very large class of work, namely, that turned out from capstans, rotary grinders, drilling machines, etc. The machine was set up to cut near the minimum size on a shaft, and the wear of the tool brought it in time near to the maximum size, the converse being the case with regard to holes. The maximum rate of wear of the tool would be in the earlier part of the operation and would get slower towards the end. This could be shown graphically, as in Fig. 10; the curve, however, made no pretence to being correct. The distance OB represented the wear of the tool to some convenient scale and would be something less than half the limit of the work. OD was the time to wear the tool out, OC represented the proportion of work which took advantage of more than half the limit, and CD the larger proportion which was within less than half the limit.

He thought that the "hole basis" was essentially the right

Fig. 10.



system and that the "shaft basis," if necessary, should be a variation from general practice, or it might be that bright bar could be made to fall in with either system, as suggested by Mr. Hedley Thomson. In his opinion, the tables of limits for running fits and shafts should be divided into two entirely separate parts. First, a table of fine and of coarse limits for work under normal conditions, that is, where the only heating, if any, was due to friction. Second, a table or tables for work where heat would be taken up from some outside source. His reasons for this were twofold: That allowances for expansion had no connexion with a $\sqrt{D}$ law, but should follow a straight-line curve; and that where a running fit was wanted under normal conditions, that is, with no external heat, the limits should be allowed to overlap.

He hoped that, when the B.E.S. Association's Report was issued, it would be a really authoritative work which would meet with the general approval of engineers. He put forward the following suggestions :—

Holes.—Two sets of limits on unilateral system. Second-grade limits to overlap first-grade limits; with a proviso that fine limits only were to be used for transition fits.

Shafts: Running Fits under Normal Conditions.—Two sets of limits, second-grade to overlap first-grade.

Running Fits under Heat or Abnormal Conditions.—Two sets of limits based upon the last-named fits, plus an allowance according to a straight-line law for expansion. Limits to overlap or not as thought advisable.

Transition Fits.—No comment needed.

Interference Fits.—In two sets of limit tables stating the range of tensile for which they were suitable, based on a law proportional to D.

Mr. A. A. REMINGTON wrote that he thought it was impossible to make a practicable combination of the unilateral and bilateral systems, unless the bilateral were limited to one degree of tolerance. If tolerances in the two systems were both to be expanded, the fact that one expanded outwardly and the other both outwardly and inwardly at the same time, precluded the possibility of compromise. The logical correctness of the unilateral system which had been shown could, however, to some degree be sacrificed or a semi-correct series of holes added to it so as to form a compromise, and it was possible that an addition of this nature would enable a standard uniform system to be adopted without precluding the possibility of the complete but gradual general adoption of the unilateral system.

Some systems that were bilateral, in so far as distribution of tolerance was concerned, were not bilateral in regard to expansion of tolerance, inasmuch as the tolerances were not expanded equally above and below the nominal. The Newall system was an example of such a system, the two grades of hole being as shown superimposed in

Fig. 11. Such a system could not be termed bilateral, and in fact, if the inward portion of the tolerance were made the same for both grades of hole (a comparatively slight modification, except in the smaller sizes) it would be unilateral based on a false nominal.

If then in addition to two or three grades of hole on a unilateral basis, such as shown in Fig. 12, a second series of holes, the first being bilateral and based on the first tolerance steps, and the second and third expanding outwardly from it, we should at once provide a means of compromise that would overcome the difficulty of a compromise between the unilateral system and such systems as the Newall. The first or bilateral hole would provide the same tolerances as the first unilateral hole, the tolerances of the others following similar steps, thus forming what might conveniently be termed a semi-lateral series of holes. Such a series was shown graphically in Fig. 13.

In attempting to provide a standard system, it seemed useless to attempt to evade the completion of the problem by stopping short at running fits, as undoubtedly the standard system must provide a sufficient series of transition and interference fits, and it was probable that there was greater need for the standardization of these than of clearance fits. The difficulty of dealing with these was admittedly greater, but the necessity was at least as great, probably greater also. The chief difficulties presumably lay in : (1) The inevitable fineness of the permissible tolerance ; and (2) the effect of length of engagement and hardness of the metal, and perhaps also smoothness of surface, on the tightness of the fit. The system, in order to overcome these difficulties, should provide a sufficient number of series that would provide a series of fits of increasing tightness, possibly in the case of transition fits basing two distinct series on the two recognized laws for tolerance, and leave it to the engineers who would use the system to prescribe which series should be used to get the desired results in each particular case.

The first unilateral hole and the bilateral hole would probably only be used in connexion with transition fits, including the cases of no positive and no negative allowance respectively, as shown by

FIG. 11.—*Newall First and Second Grade Holes Superimposed.*

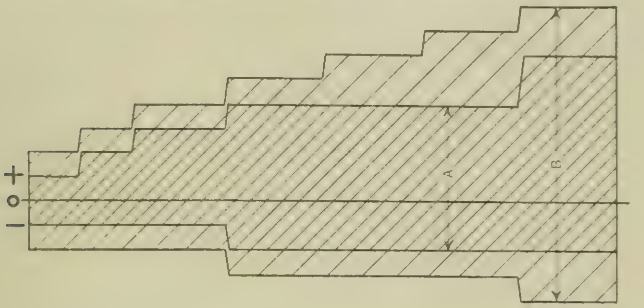


FIG. 12.—*An Example of a Series of Unilateral Holes.*

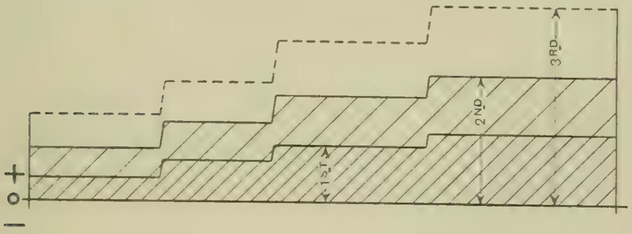
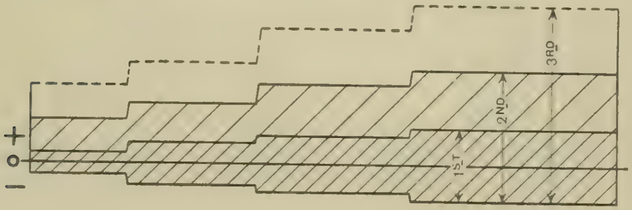


FIG. 13.—*An Example of a Series of "Semi"-lateral Holes with the same Tolerances as the Unilateral Holes shown in Fig.* 12.



Figs. 14 and 15, and here the two parallel series of holes would be a considerable convenience, as the same shaft would produce, say, a sliding fit in one hole and a light drive fit in the other, and so on. It was probable that, in cases where the third grade of hole was permissible, such as in coarse running fits, and possibly also in tight shrink fits, it would be immaterial whether the third grade unilateral or the third grade semi-lateral hole was used, as the difference in practice would be so small.

FIG. 14.—*Unilateral Hole with Limiting Cases of Shaft.*

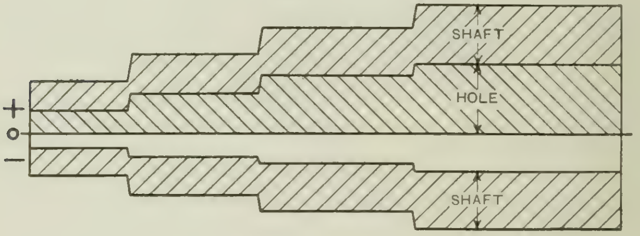
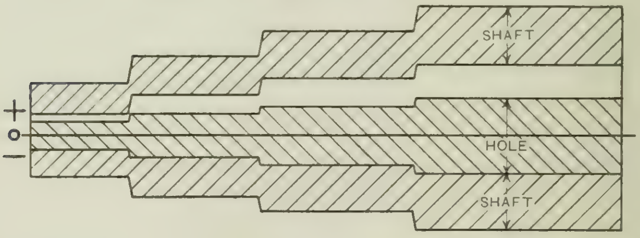


FIG. 15.—"*Semi*"*-lateral Hole with Limiting Cases of Shaft.*



In considering these matters, it must always be borne in mind that the extremely fine measurements it was now possible to make with such facility, were not a serious factor except in the smaller sizes and in the finer grades of fit, which included the transition fits and those fits which provided no allowance. Except in these cases, tolerances could be considerable, and except in small sizes quantities less than 0·0005 inch and often even 0·001 inch might very generally be ignored.

Mr. GEORGE W. WATSON wrote that he feared he could not agree with Sir Richard Glazebrook in this matter, as, from the practical point of view, he thought that everything was in favour of the adoption of the bilateral system, and he hoped that the merits of this system would be given the most careful consideration. Early in 1917 he became responsible for the design and construction of engines for tanks, and he found that the five different manufacturers of the same type of engine were working to five different sets of limits. Some were working to the bilateral and the others to the unilateral. A meeting was called of the manufacturers concerned and he expressed his views, the result being that they unanimously adopted a well-known bilateral system, which worked so successfully that three months later he was able to collect various parts of an engine from the different manufacturers, and have them assembled into a complete engine without the use of a file or any other fitting whatever. He carried this test to the extent of taking a top half of a crank-case from one manufacturer and the bottom half from another, demonstrating the high degree of interchangeability which was secured. He did not deny that such a degree of interchangeability could have been obtained with the unilateral system, but he claimed that the adoption of the bilateral system enabled him to get into quantity production of these engines much earlier than could have been the case with the unilateral system, because he was able to use commercial standard reamers which could be bought "over the counter." These invariably had a plus and minus tolerance.

He thought it would be a very great pity if the unilateral system were adopted as a standard, because he felt sure that such a standard would simply be ignored in the same way that the old British Standard limits had been, in which standard the shaft was taken as a basis. The Engineering Standards Committee of that day made a very serious blunder, and he hoped that they would not now make an equally serious blunder in adopting the unilateral system.

Sir **Richard Glazebrook** wrote that there were one or two matters mentioned in the Discussion in London which he omitted to notice in his brief reply and which seemed to call for some remarks.

Mr. Taylor was mistaken if he imagined the writer expected a draughtsman to have recourse continually to a formula. The tolerances and allowances specified would be fully tabulated; the formula was only used—to quote Mr. Taylor—"to get harmony and proportion in the series."

Again, the length of the ranges and the size of the steps were both determined by definite decisions of the Committee, and Mr. Dumas, in his remarks, gave the reason for selecting what Mr. Taylor considered unnecessarily small increments. If we were going to keep the tolerance up to a maximum, it meant that that tolerance must change by small increments as the diameter changed; two gauges were required, each of which had a tolerance of, say, 0·0003 inch. We might provide that, over the range 3 inches to 6 inches, there was a difference between them of 0·004 inch or that, from 3 inches to 4 inches, the difference was 0·003 inch, from 4 inches to 5 inches it was 0·004 inch, and from 5 to 6 it was 0·005 inch. In either case the difficulties of manufacture were the same; in the second case we got the better fits and the greater margin for wear. There was less for the draughtsman to remember in the first case; but he was not to trust his memory but to refer to his Tables. Still, if Engineers considered the ranges too short, it was quite easy to increase their length. He might remark, however, that a reference to Fig. 2 (page 480) reproduced from his Thomas Hawksley Lecture showed that, in the principal systems already in vogue, steps and ranges of about the length proposed in the draft Report had been adopted.

This led to a further point: the $\sqrt{D}$ law for allowances. It was based originally on the practice of Messrs. Armstrong Whitworth, as explained by Mr. Matthews, and on the measurements of Mr. Attwell. It had been followed in all the existing systems and was the basis of the proposals recently adopted in Germany and Switzerland. It was discussed in a recent paper by Dr. Kuhn

(Zeits. des Ver. deut. Ingenieure), and he stated that it had proved satisfactory as a basis—other laws were tried and rejected.

The question of reamers was raised by one speaker. The difficulty could be met by a suitable specification for the standard sizes of reamers, and it was understood that the Committee dealing with this question were prepared to frame their recommendations so as to meet it.

The Institution of Mechanical Engineers.

PROCEEDINGS.

May 1921.

An Extra General Meeting was held at The Institution, London, on Friday, 27th May 1921, at Six o'clock p.m.; Captain H. Riall Sankey, C.B., C.B.E., R.E. (ret.), *President*, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the following 62 Candidates had been duly elected:—

MEMBERS.

Biggin, Frank,	Sheffield.
Bulleid, Charles Henry, O.B.E., M.A.,	Nottingham.
Emerton, John Robinson,	Hull.
Henderson, Thomas, Major, A.O.D.,	Melbourne.
I'Anson, Hugh Coventry, Captain, R.A.S.C.,	London.
Jenkins, David,	London.
Kemish, Herbert,	Colombo.
Parez, William Tempest, Eng.-Commr., R.N., ret.,	London.
Penn, Alfred Edward, Captain, R.A.F.,	London.
Stamford, Alfred Richard, Major, R.A.O.C., I.O.M.,	Dover.
Windle, Sydney Robert,	Doncaster.

ASSOCIATE MEMBERS.

Almond, William Charles,	Woolwich.
Atkinson, James William,	Sunderland.
Bannister, Alfred Harry George,	Croydon.
Barker, Alfred William Kent,	Cambridge.
Burr, Percy Sellers,	Croydon.
Carr, Reginald Sidney,	London.
Coade, Loftus George,	Birmingham.

David, William Thomas, M.A., D.Sc.,	Cardiff.
Donkin, Cyril Bryan,	Birmingham.
Dunell, Hubert, O.B.E.,	London.
Dyson, Fred,	Halifax.
Fenner, Louis Archibald,	London.
Goacher, Walter,	Stoke-on-Trent.
Harris, Harry Edwin,	Newcastle-on-Tyne.
Kirke, Percy St. George, M.A.,	London.
Lingard, Alexander,	Lincoln.
MacIvor, Douglas Tait,	Greenhithe.
Maclean, John,	Port Said.
Mather, Raymond Alexis,	Bara Hapjan P.O.
Petrie, Paul Telford,	Manchester.
Sadler, Robert William,	London.
Trost, Henry Rudolf,	Coventry.
Wild, William Robert,	Colombo.
Withers, George Mould, M.B.E.,	Birmingham.

ASSOCIATES.

Hartfree, George Bertram,	Godalming.
Hoey, George McCausland,	Allahabad.

GRADUATES.

Ackery, Edward Melville, A.F.C.,	London.
Beer, Edward Valentine,	London.
Bird, George,	London.
Boxall, Thomas George William,	Reading.
Braham, John Edgar,	London.
Bridgman, Rex Labdon,	Paignton.
Bucka, Philip,	London.
Collot, Henry Gordon,	London.
Deacon, Henry James,	London.
Dimmock, Alfred Lancelot,	London.
Griffiths, Arnold Wilmot,	Pembroke Dock.
Hawksworth, John William Martin,	London.
Hedley, Raymond Cecil Hall,	London.
Hurley, Philip,	London.
Jones, John Cyril,	Loughborough.
Lyon, Gerald,	Manchester.
Manchée, Henry Victor,	London.
Millar, Raymond Henry,	London.
Mitchell, Alexander Millar,	London.
Purnell, Howard George,	Loughborough.
Scotland, Lawrence James,	London.
Souza, Manuel Chambers de,	Bournemouth.
Staff, Sidney Hartley,	London.
Tamplin, George Roff,	London.
Waters, Herbert Reginald, B.Sc.,	Wakefield.

The President announced that the following two Transferences had been made:—

Associate Member to Member.

Webb, Herbert Arthur,	London.
Williamson, Edward,	London.

A Lecture * on "The World's Money System" was then delivered by Mr. J. G. Graves, of Sheffield.

On the motion of Dr. H. S. Hele-Shaw, F.R.S., *Vice-President*, seconded by Mr. William H. Patchell, *Vice-President*, a hearty vote of thanks was accorded to Mr. Graves.

The Meeting terminated at about Half-past Seven o'clock. The attendance was 54 Members and 7 Visitors.

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* This Lecture will not be published in the Proceedings.

MEMOIRS.

George Allan was born at Aberdeen on 18th August 1838. He served his apprenticeship at the Elswick Works, Newcastle-on-Tyne, and became works manager of the Ordnance Department. In 1875 he took up the post of general manager of the Savile St. Foundry and Engineering Co., Sheffield, which he held until 1883, when he became managing director of the New British Iron Co., near Birmingham. While there he brought out a composite steel-plate, used for burglar-proof safes, etc. In 1894 he left the Midlands and was engaged for some years in London with a firm of consulting engineers, after which he was employed with the Bowesfield Steel Co., at Stockton, until his retirement in 1907. His death took place at Jesmond, Newcastle-on-Tyne, on 11th January 1921, in his eighty-third year. He became a Member of this Institution in 1875.

William Milward Allen was born in York in 1841. He was educated at Bramham College, Yorkshire, and served an apprenticeship of five years at the locomotive works of the North Eastern Railway at York. From 1861 to 1866 he was in the Company's drawing-office and assistant to the locomotive engineer. In the latter year he was engaged under the late Mr. R. B. Longridge, Chief Engineer of the Boiler Insurance and Steam Power Co., Ltd., Manchester, and in 1879 he was appointed an assistant engineer of the Boiler Department of the Company. This position he held until his retirement in 1906. His death took place in Manchester on 11th June 1920, at the age of seventy-nine. He became a Member of this Institution in 1882.

Thomas Ashbury was born at Davyhulme, near Manchester, on 9th February 1836. He was the oldest member of the engineering profession in the Manchester district, and for 54 years he was identified with the Manchester Association of Engineers, holding the office of President in 1883–4. He was at one time general manager of the Ashbury Carriage Co., Openshaw, Manchester. His death took place in Manchester on 11th September 1920, in his eighty-fifth year. He became a Member of this Institution in 1873; he was also a Member of the Institution of Civil Engineers.

JABEZ ATTWOOD was born in 1844. He served his apprenticeship with Westwood and Wright, of Dudley, from 1858 to 1864, and then went as improver to James Watt and Co., Soho, Birmingham. Two years later he was employed at the Great Western Railway Works, Wolverhampton, and in 1876 entered into partnership with Mr. W. Jones, of Stourbridge, as heating and ventilating engineers. The partnership having been dissolved in 1886, Mr. Attwood continued at his works in Stourbridge, and was the inventor of many improvements in valves, joints, radiators, etc. His death took place at Stourbridge, after an operation, on 1st December 1920, in his seventy-seventh year. He became a Member of this Institution in 1898.

Sir JAMES BENJAMIN BALL was born at Cowes, Isle of Wight, on 9th March 1867. He was articled to Mr. Joseph Hall, Civil Engineer, and began his career on the staff of the Great Northern Railway in 1890. In 1895 he was engaged under Mr. Elliott-Cooper (afterwards Sir Robert Elliott-Cooper, K.C.B.) as resident engineer on the construction of the Lancashire, Derbyshire, and East Coast Railway and became engineer to that line in 1899. On the absorption of that railway by the Great Central Railway in 1907, Mr. Ball (as he then was) was appointed assistant engineer for new works to the Great Central Railway Co., and whilst holding that position was mainly responsible for most of the important civil engineering works carried out, including the rebuilding of the Carriage and Wagon Works at Dukinfield, the Gravity Concentration Yard at Wath, the Ardwick and Hyde Junction and Torside to Woodhead Widenings, and the lay-out of the permanent-way, bridges and equipment works in connexion with the new deep-water dock at

Immingham then under construction. This latter included the power station and ferro-concrete granary, as well as a large number of ferro-concrete bridges both there and elsewhere on the Great Central system. In 1911 he was appointed Engineer-in-Chief of the Railway. Chief amongst his works in this capacity may be mentioned the new railway and roadway bridge over the River Trent at Keadby, in which he was the first engineer in this country to adopt the Scherzer principle for a bridge of that magnitude, which contains an opening span of 160 feet and is the largest and heaviest lifting span in Europe, having a total moving mass of over 3,000 tons. In 1917 he severed his connexion with the Great Central Railway to succeed the retiring chief engineer of the London, Brighton and South Coast Railway in a similar position, but his services were very quickly requisitioned by the Government as Controller of Timber supplies, and his valuable services in that capacity were rewarded by the honour of knighthood in 1918. His death took place suddenly from heart failure on 16th September 1920, at the age of fifty-three. He became a Member of this Institution in 1914; he was also a Member of the Institution of Civil Engineers.

ARTHUR EDWARD BENNETT was born at Leicester on 28th June 1873. He was educated at Mill Hill School, London, and at the City and Guilds of London College. After serving an apprenticeship of three years with Messrs. Gimson and Co., Leicester, he became a partner in the firm of Webster and Howarth, machine-tool makers, Coventry, of which the firm of Webster and Bennett, Ltd., is the successor. His death took place at Leicester on 8th July 1920, at the age of forty-seven. He became a Member of this Institution in 1902.

TOMYNS REGINALD BROWNE, M.B.E., was born in Jersey, C.I., on 30th August 1854. He received his technical training in the locomotive works of the Midland Railway at Derby, and then joined the inspecting staff of Sir A. M. Rendel and Sons, Westminster, consulting engineers to the India Office for Indian State and Company-worked railways. In 1878 he went to India as assistant district locomotive superintendent on the East Indian Railway, becoming in due course district loco. superintendent, and deputy locomotive superintendent. In 1898 he was appointed rolling stock superintendent at Howrah, and planned and equipped the new Carriage and Wagon Works at Lilloah, introducing electric drive. Four years later he returned to Jamalpur, becoming Locomotive Superintendent, and held this position until his retirement in 1908. He retired from the East Indian Railway Volunteer Rifles with the rank of Lieut.-Colonel, and held the Volunteer Officers' Decoration. During the War he was engaged at Woolwich Arsenal, under the Ministry of Munitions, for which services he was made a Member of the Order of the British Empire. His death took place suddenly at Tenterden on 14th December 1920, at the age of sixty six. He became a Graduate of this Institution in 1874 and a Member in 1879.

CHARLES JOHN BOWEN COOKE, C.B.E., was born near Peterborough, on 11th January 1859, and was educated at the Preparatory School, Cheltenham, and King's College School, London, and later on the Continent. He entered the Crewe Locomotive Works as a premium apprentice in 1875, and afterwards became a pupil of the late Mr. F. W. Webb. On the completion of his pupilage he was appointed assistant to the Superintendent of the Running Department of the Southern Division of the L. and N.W. Railway, and was afterwards assistant to Mr. G. Whale, when he took over the entire control of the Running Department. When Mr. Whale was made Chief Mechanical Engineer, Mr. Cooke became Superintendent of the Running Department, Southern Division, and on Mr. Whale's resignation in 1909, he was appointed Chief Mechanical Engineer.

Mr. Cooke was responsible for the introduction of mechanical coaling and ash-handling plants on British Railways; also of 4-cylinder simple locomotives on the L. and N.-W. Railway, and many new classes of engines, of which probably the most famous is the "Sir Gilbert Claughton" class, brought out in 1913. During the War he was a member of the War Manufactures Sub-Committee of the Railway Executive Committee, in which capacity he performed valuable services to the country, and a member of the Machinery and Metals Committee of the Inventions Panel appointed by the Ministry of Munitions. At Crewe a type of tractor was developed out of a Ford car, armoured trains were built, a great deal of forged and other work turned out in addition to small material, overhead cranes, rails, etc. He served on several Committees connected with the Railway Executive Committee, the Ministry of Munitions, and Ministry cf Transport. He paid several visits to France during the War in connexion with the working of the military railways, and visited America in 1917 to purchase material for British Railways.

Besides numerous articles on railway engineering subjects, he wrote several books on locomotives which were accepted as standard works, and played an important part in the training of students. He was Mayor of Crewe during 1918–19, and served on the Cheshire County Council. He was also a Justice of the Peace, and Major in the Engineer and Railway Staff Corps, R.E. (T.F.). Early in 1918 the King conferred upon Mr. Cooke the Commandership of the British Empire in recognition of his services to the country. His death took place at Falmouth on 18th October 1920, in his sixty-second year. He became a Member of this Institution in 1912; he was also a Member of the Institution of Civil Engineers.

Frederick Lister Croft was born in Bradford on 30th September 1857. He was educated at local schools, and commenced work in Bradford at an early age. With the exception of a short period in the United States, he spent the whole of his business career in that city. At the age of twenty-nine he founded The Patent Pulley Co., Croft and Perkins, power transmission specialists, now styled Crofts (Engineers), Ltd., Thornbury, Bradford. The company commenced with the manufacturing of Mr. Croft's wrought-iron pulley, the original staff consisting of four men. The business grew very rapidly, and at his death the works covered ten acres and employed over 1,000 hands. During his career he held many important offices, namely, President of the Bradford Engineering Employers' Federation, Chairman of the

Engineering Section of the Bradford Chamber of Commerce, and he had been a Member of the City Council. His death took place at Morecambe on 5th November 1920, at the age of sixty-three. He became a Member of this Institution in 1903.

REGINALD THOMAS GREEN CROSS was born on 15th December 1866, and served an apprenticeship in the works of the London and North-Western Railway at Crewe. In 1893 he went to Assam as engineer and assistant manager to the Brahmapootra Tea Co., and during the following years he was engaged in a similar capacity on various tea estates. His death took place suddenly in Assam on 24th May 1920, at the age of fifty-three. He became an Associate Member of this Institution in 1905.

ROBERT SCOTT EASTON was born in Glasgow on 28th March 1873. He was educated at the Glasgow and West of Scotland Technical College, and served an apprenticeship of six years with F. Braby and Co., Ltd., Glasgow. On its completion in 1892 he was engaged in the drawing-office of Francis Morton and Co., Ltd., Liverpool, for five years, and in 1897 became chief works draughtsman to A. and J. Main and Co., Ltd., Glasgow. He went to India in 1901 as engineering draughtsman with Burn and Co., Ltd., Howrah, and acted in a similar capacity with Jessop and Co., Ltd., Calcutta, from 1902–6, when he took up the post of engineering draughtsman with Geo. Gahagan and Co., Bombay. Three years later he became General Manager to Turnbull Brothers, Ltd., Calcutta, for whom he carried out several large contracts. His death took place on 4th October 1920, at the age of forty-seven. He became an Associate Member of this Institution in 1910.

DAVID CORSE GLEN was born in 1863, and was educated in Glasgow. He served his apprenticeship from 1879 to 1884 with Glen and Ross, Greenhead Engine Works, Glasgow, where he was afterwards employed as assistant foreman. During that period he also attended technical classes at the Andersonian College. From 1886 to 1891 he was engaged as draughtsman successively at the

Clyde Loco. Co., Duncan Stewart and Co., Alley and MacLellan, and Watson, Laidlaw and Co., all of Glasgow. He then entered into partnership in the Ingliston Foundry Co., Greenock, and in 1895 was appointed advisory and purchasing engineer on the staff of Matheson and Co., London, resigning this position in 1910 and commencing practice as a consulting engineer. In 1915 he was appointed advisory engineer and, later, general manager to J. Whittall and Co., Ltd., but returned to private practice in 1919. For many years he was also a director of Macfarlane, Strang and Co., Ltd., Glasgow. His death took place on 14th August 1920, at the age of fifty-seven. He became a Member of this Institution in 1898.

Wilson Hartnell was born at Stroud, Glos., on 27th June 1839. He spent his boyhood at St. Mary, Scilly Isles, where his father was for some time curate-in-charge, and from whom he gained his scientific knowledge. He served his apprenticeship with Messrs. Ferraby, of Stroud, and from there he went to Messrs. Bryan Donkin, of Bermondsey, and later to the drawing office of Messrs. Sharp, Stewart and Co., Manchester. After some time spent in Edinburgh, and with Messrs. Kitson and Co., of Leeds, he began in business for himself at the Volt Works, Leeds, in 1871. Among his many inventions may be mentioned the Hartnell Governor, on which subject he read a Paper before this Institution in 1882. In January, 1920, he retired from active work. His death took place in Leeds on 10th November 1920, at the age of eighty-one. He became a Member of this Institution in 1872.

Jacob Higson was born at Clifton, Lancs., on 29th March 1837, and was educated at the Owens College. After seeing service in the Crimean War, he returned to Manchester, and founded the firm of J. and P. Higson, mining engineers, of which he was the senior partner. He assisted in laying the first electric cable between the British Isles and America in 1858, but his work lay principally with mining. He was prominently connected with the Lancashire coalfield and with the collieries of South Wales, and was a director of many mining companies with interests in Spain, Portugal, North and South America, and South Africa. His death took place at Northwood, Middlesex, on 18th November 1920, in his eighty-fourth year. He became a Member of this Institution in 1879 ; he was also a Member of the Institutions of Civil Engineers and Mining Engineers.

JAMES HUNTER was born at Oakbank, Midlothian, on 4th February 1871. His early education was received at a local school, and in 1884 he became an apprentice fitter at the works of Henry Balfour and Co., Ltd., Leven, Fife, and remained in their employment until 1894. During the next six years he acted as marine engineer with the British India S.N. Co., subsequently obtaining a 1st Class Engineer's Certificate. In 1899 he re-entered the employment of H. Balfour and Co., as draughtsman, becoming chief draughtsman in 1903, which post he held until 1912, when he was appointed works manager. In 1919 he was appointed General Manager, holding the position until his death, which took place at Leven on 9th June, 1920, at the age of forty-nine. He became a Member of this Institution in 1917.

ARTHUR HENRY CARLETON L'ESTRANGE was born at Kevinsfort, Sligo, on 8th July 1866. He served an apprenticeship of five years with Messrs. Harland and Wolff, Belfast, and of two years with Messrs. Scott Russell, Loughborough. He then went to sea for eight years and obtained the Board of Trade Certificate as Extra 1st Class Engineer, when he started in business in London as Superintendent Engineer and Surveyor. In 1905 he opened works in London as a motor engineer, and later in Dublin and Sligo, in which latter place he developed a system of motor tillage. On the outbreak of the War he organized and managed recruiting tours, and then engaged in the manufacture of munitions at his works in Sligo. In 1917 he was appointed a consulting engineer to the Director of Naval Ordnance, and was demobilized in July, 1919. His death took place suddenly at Ardnagary, Sligo, on 16th December 1920, at the age of fifty-four. He was elected a

Member of this Institution in 1905, and was a Member of the Institution of Naval Architects.

Sir John McLaren, K.B.E., was born at Hylton Castle, near Sunderland, on 1st April 1850. He was educated privately, and in 1866 was apprenticed to Messrs. Black, Hawthorn and Co., Gateshead, makers of locomotives, mining and marine machinery. On the completion of his time he became manager of the Ravensthorpe Engineering Co., of Mirfield, Yorks, and in 1876, in partnership with his brother Henry, he founded the firm of J. and H. McLaren, Midland Engine Works, Leeds, of which he was the Chairman at the time of his death. He became a prominent member of the Engineering Employers' Federation, and at one time was Chairman of the Agricultural Engineers' Association. He served on the Royal Commission for the International Exhibitions at Brussels, Turin, and Rome, and was President of the Leeds Chamber of Commerce in 1918–19. Soon after the outbreak of the War he became Chairman of the Board of Management of the first National Ordnance Factories, which were started in Leeds before the foundation of the Ministry of Munitions. For his services in connexion with this work he was created a Knight of the Order of the British Empire in 1919. He was also a Justice of the Peace. His death took place in Leeds on 12th October 1920, at the age of seventy. He became a Member of this Institution in 1903.

Cree Maitland was born in Glasgow on 12th June 1865. He was educated at Dollar and Glasgow Academies. For two years he was apprenticed to electrical engineering with Anderson Munro, which firm was the first to light up a private house in Scotland with electricity. He then served an apprenticeship at the locomotive works of Dübs and Co., Glasgow, and of the Caledonian Railway Co. After two years' travelling in New Zealand and Australia he was appointed in 1890 manager and locomotive superintendent of the Sungei Ujong (Malay Peninsula) Railway Co., which position he held for ten years. He then became manager in Scotland for L. Loewe and Co., of London and Berlin, and six years later took up the position of general manager of the Glasgow Crane Works, resigning in October, 1910. He was always interested in lubrication matters, and formed a company in 1912—The Menno Compressed-Air Grease-Cup Co., Ltd.—for the manufacture of compressed-air lubricators pressed out of steel and brass, becoming managing director. This position he held until his death, which took place in London on 1st July 1920, at the age of fifty-five. He was a Member of this Institution from 1898 to 1907, and was re-elected in 1913.

The Right Hon. Sir WILLIAM MATHER, LL.D., was born in Manchester on 15th July 1838. When only twelve years of age he persuaded his father to allow him to commence his apprenticeship at the Salford Ironworks, which had been founded more than a century ago. Three years later he was sent to the Continent to continue his education, and after a year or two he returned to Salford to complete his apprenticeship. At the age of twenty he assisted in the management, and four years later was admitted a partner with his uncle, Colin Mather, and William Platt. At the age of thirty, the elder partners having retired, he took over the entire control of the business, and subsequently took into partnership Mr. John Platt. He was the first amongst British manufacturers to establish the forty-eight hours week in 1893. He was an authority on every detail connected with the original line of business of the firm, the manufacture of machinery for the equipment of calico bleaching, printing, dyeing, and finishing works, and many of his inventions are in general use to-day. He was a great authority on Artesian Well Boring, on which subject he contributed a Paper* to this Institution. In order to increase the business of his firm he travelled extensively, both in Russia and the United States. In the latter country in 1883 he made a detailed study of the means for technical education on behalf of the British Government, and the result of his inquiries was largely instrumental in the introduction of the Technical Instruction Bill of 1889, which Mr. Mather, then in Parliament, did much to place on the Statute Book.

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* Proceedings I.Mech.E., 1869, p. 278.

When electrical engineering was in its infancy he acquired the manufacturing rights in the Edison dynamo, and started an electrical department at the Salford Iron Works. This invention was soon improved greatly by the late Dr. John Hopkinson and his brother, Dr. Edward Hopkinson (Past-President). On his last visit to the United States, when he received the degree of LL.D. at Princeton University, he obtained the rights for manufacturing a reinforced-concrete construction, which has developed into the Indented Bar and Concrete Engineering Co., Ltd. In 1891 he established the Chloride Electrical Storage Co., and in 1895 he founded the Castner-Kellner Co., for the manufacture of caustic soda and chlorine electrolytically, and of each was the first chairman. In 1889 the first London tube railway, known at that time as the City and Southwark Subway, was under construction, and the intention was to work it by wire rope A scheme was prepared by Dr. Edward Hopkinson, at that time Mr. Mather's junior partner, for working the line by electric locomotives, which was carried out by Messrs. Mather and Platt, and the line was opened for traffic in 1890 by King Edward, then Prince of Wales. This line was afterwards extended and known as the City and South London Railway. He took a great interest in educational matters, and as early as 1873 he started the Salford Iron Works Science School, at which all the apprentices were required to attend in the evenings. He was the first President of the Association of Technical Institutions. In 1902 he received the honour of Knighthood, and 1910 he became a Privy Councillor. His death took place at Bramble Hill Lodge, his residence in the New Forest, on 18th September 1920, at the age of eighty-two. He became a Member of this Institution in 1867.

RAYMOND PAYNE was born at Brampton, Northamptonshire, on 27th June 1875. He was educated at Ackworth and Sidcot Schools, and later at the Northampton Technical School. His apprenticeship was served with Grose, Norman and Co., Northampton, and he then spent two years in the shops of Fraser and Chalmers, Erith. In 1897 he visited the West Australian Goldfield, and from there went to New Zealand to join his brother, F. W. Payne, who was employed on dredge-designing for alluvial gold in New Zealand. Having supervised the construction in New York of gold-dredging plant for New Zealand, he returned to London, and became a partner in the firm of F. W. Payne and Co., dredge-mining engineers, of London and Dunedin. He designed some of the largest tin dredges operating in the Malay States. His death took place at Westcliff-on-Sea, after a long illness, on 13th June 1920, in his forty-fifth year. He became an Associate Member of this Institution in 1905, and a Member in 1915.

JOHN TEBBUTT PLOWRIGHT was born at Nottingham on 27th July 1869. He received his scholastic education at Gosberton Hall, Lincolnshire, and at Nottingham High School. In 1885 he commenced his apprenticeship with Messrs. Sharp, Stewart and Co., Manchester, and concluded it with Messrs. J. and G. Thompson, Clydebank. He then joined Messrs. Thomas Wilson and Sons, of Hull, as sea-going engineer, and sailed with them for nine years. In 1900 he became chief engineer in the marine department of the Southern Nigerian Protectorate, and was for nine years chief of the Government yacht "Ivy." He took an important part in the suppression of the Bibicala rising in 1903, for which he received the King Edward Medal for gallantry. In 1911 he retired owing to ill-health contracted through the climatic conditions of the country. For a period during the War he served as a Government Inspector in the Aeronautical Department. After prolonged ill-health his death took place at Hull on 10th September 1920, at the age of fifty-one. He became a Member of this Institution in 1912

Captain PERCY TOWNLEY RAWLINGS, D.S.C., R.A.F., was born on 22nd September 1887. He was educated at Westminster School and Cambridge University, where he obtained honours in the Mechanical Sciences Tripos. In 1910 he went to Woolwich Arsenal as advanced workshop student, and in the following year he obtained a Commission in the Royal Engineers (S.R.). In 1912 he entered the Public Works Department of the Sudan Government, and during

1913–14 acted as engineer to the Egyptian Irrigation Service on the construction of the Blue Nile Dam. On the outbreak of the War he was sent to France, as Lieut. R.E., in the 2nd Field Co., being transferred in the following year to the R.N.V.R., for engineering duties with the R.N.A.S. In 1917 he flew to Constantinople in a Handley-Page machine, and bombed the *Goeben*, for which he received the D.S.C. His death took place, as the result of an aeroplane accident, on 26th May 1919, at the age of thirty-one. He became an Associate Member of this Institution in 1916.

FREDERICK GEORGE ROSS was born at Basingstoke on 5th April 1849. He served an apprenticeship at the Mina de Santo Domingo, Portugal, and completed it at the Salisbury Iron Works, Salisbury. He next returned to Portugal as engineer and millwright at Oporto for a short time, and then sailed as engineer on various steamers, subsequently becoming chief engineer to Messrs. Rathbone Brothers on the Star Line of steamers. After holding for a short time the post of superintendent engineer to the Perim Coal Co., Perim, he was appointed engineer-in-charge of the Indian Manufacturing Co.'s mills at Bombay. In 1901 he started in business in Bombay as consulting engineer and acted as Lloyd's Surveyor. His death took place at Bombay on 25th March 1920, in his seventy-first year. He became an Associate Member of this Institution in 1901.

HAROLD SMITH, M.B.E., was born at Blackpool on 3rd June 1879, and was educated at King William's College, Isle of Man. He served his apprenticeship at the Salford Iron Works of Messrs. Mather and Platt, Ltd., and on its completion in 1904 became works manager of their electric motor department. During this latter period he was largely responsible for the removal of the firm's electrical manufacturing departments to the Park Works, Newton Heath. In 1907 he went to Canada, and worked as assistant superintendent, and later, superintendent, of the shops of the Montreal Light, Heat and Power Co., until December 1909. From that date he took over the works managership of the Canadian Crocker Wheeler Co., Ltd., and built and equipped their new works at St. Catherine's, Ontario. He returned to Messrs. Mather and Platt's employ early in 1912, as assistant works manager of the Park Works. Among the inventions he brought out may be mentioned that of an interpole variable-speed electric motor, in 1906, and an improvement in the construction and manufacture of steam-heated drying cylinders. During the War he devoted his time almost entirely to the production of war munitions, and the heavy and continuous work so enfeebled his constitution that he contracted influenza, from which he died on 27th December 1918, at the age of thirty-nine. He became a Graduate of this Institution in 1904, an Associate Member in 1905, and a Member in 1916.

GEORGE TANGYE was born at Illogan, near Redruth, Cornwall, on 17th September 1835, being the youngest of six sons of Joseph Tangye. Having received an early training in the local school, he was sent to complete his scholastic education at a Friends' School in the Mendip Hills. After working as a clerk at the works of Mr. Thomas Worsdell, in Birmingham, where his brother Richard—afterwards Sir Richard—was also employed, he joined with his brothers in starting in business in 1857 as machinists at 40, Mount Street, Birmingham. Owing to the growth of the business a new factory had to be built in 1859. A few years later the idea was conceived of designing steam-engines in which the various parts could be made interchangeable. The result was that the well-known Tangye engine came into existence, which was shortly followed by their high-speed governor. A still larger factory was therefore required, and finally the Cornwall Works, Soho, close to the historic foundry of Boulton and Watt, was erected. In 1881, when the firm was turned into a limited liability company, George Tangye was made vice-chairman and finally Chairman of the company when his brother—Sir Richard Tangye—died in 1906. For many years he lived at Heathfield Hall, which was formerly the home of James Watt. He carefully preserved, in the condition in which the great inventor had left it, the garret in which he had worked; and George Tangye was responsible for the fine collection of relics of Boulton and Watt, which he finally gave to the City of Birmingham. On the occasion of the Joint Meeting of this Institution and the American Society of Mechanical Engineers in Birmingham, he presented to the latter Society an original letter of James Watt suitably framed (Proceedings, 1910, page 808). His death took place at his residence in Birmingham on 7th October 1920, at the age of eighty-five. He became a Member of this Institution in 1875.

ROBERT SCOTT WATSON was born in Forfarshire on 25th February 1852. His early education was obtained at local schools, and he served a five-years' apprenticeship in a general engineering works from 1868 to 1873. He was next engaged on various constructional works until 1880, when he started in business as bridge and waterworks contractor. Five years later he began to specialize in refrigeration work, and in 1900 he went to New Zealand to take up the post of chief engineer at Christchurch Meat Co.'s Works. This position he held until his death, which took place suddenly on 30th June 1920, at the age of sixty-eight. He became an Associate Member of this Institution in 1911.

JOHN GEORGE WILCOX was born at Wisbech, Cambs, on 24th April 1871. He served a five-years' apprenticeship with J. Webster and Son, engineers, Wisbech, and then went to Toronto, where he acted as assistant engineer on the Lake Boats. In 1893 he returned to England to take up the post of engineer at the Wilmington Flour Mills, Hull, and two years later was engaged in a similar capacity at the North Shore Flour Mills, Liverpool. In 1900 he took up an appointment with the Liverpool Refrigeration Co., and held this until 1906, when he went to reorganize the Calcutta Ice Plant. He then started on his own account in Calcutta as a consulting and refrigeration engineer, and acted as the representative of the Liverpool Refrigeration Co., and other firms. His death took place at Bournemouth on 2nd December 1920, at the age of forty-nine. He became an Associate Member of this Institution in 1909, and a Member in 1912.

BARTLETT WRANGHAM WINDER, J.P., was born in Sheffield on

5th October 1858. He was educated at Sheffield Grammar School and the Collegiate College, and in 1874 entered the works of Messrs. Jonas and Colver, steel manufacturers, Sheffield, with which firm he was connected all his life, and was largely associated with its progress. At the outset he took up the chemical side of the industry, and soon became works chemist. Subsequently he was appointed works manager and a director of the company, and became chairman on the retirement of Sir Joseph Jonas in 1918. At the Brussels Exhibition in 1911 he was chosen as one of the three English judges of the steel section; he was also a director of Messrs. Smith and Coventry, of Manchester, and a member of the Court of Governors of the University of Sheffield. In recognition of his work the University conferred upon him the degree of Master of Metallurgy. In 1912 he was appointed a Justice of the Peace. His death took place in Sheffield on 19th July 1920, in his sixty-second year. He became a Member of this Institution in 1911.

Sir LINDSAY WOOD, Bart., was born at Killingworth Hall, Durham, in 1831, being the youngest son of Nicholas Wood, formerly a Member of Council of this Institution. He was educated at the Royal Kepier Grammar School, Houghton-le-Spring, Durham, and King's College, London. After serving his apprenticeship at the Hetton Collieries, of which his father was then manager, he received his first appointment in 1858 as viewer at North Hetton Colliery, and subsequently at the Hetton Collieries. On his father's death in 1866 he became Managing Director of the Hetton Collieries, and continued to occupy this position until the sale of the undertaking to Lord Joicey's firm in 1911. He was a director of several colliery companies, and of the Newcastle Electric Supply Co., the Hendon Paper Works, and the North-Eastern Railway Co. He was also mining engineer to the Ecclesiastical Commissioners and to Greenwich Hospital. He rendered useful service on various Royal Commissions, and was President of the Durham Coalowners' Association. He was a Justice of the Peace and a Deputy-Lieutenant, and was Sheriff in 1889. A Baronetcy was conferred on him in 1897. His death took place at his residence at Chester-le-Street, on 22nd September 1920, at the age of eighty-six. He became a Member of this Institution in 1868.

Hugh Wright was born at Stockton-on-Tees on 28th November 1884. He studied at the University of Sheffield for seven years, and during a portion of this period he served a pupilage of five years with Messrs. Newton, Chambers and Co., Ltd., Sheffield. Subsequently he was employed in their drawing office until 1908, when he became assistant engineer to Messrs. C. and W. Walker, Ltd., Donnington, Salop. In 1911 he was appointed chief engineer to the Cyanide Plant Supply Co., London, where he was engaged in the design of mining and other plant. Three years later he became General Manager to Messrs. Cochrane and Co., of Dudley, and during the War he superintended the construction of engine and condenser work for the Government. His death took place in London on 5th December 1920, at the age of thirty-six. He became an Associate Member of this Institution in 1913, and a Member in 1917.

INDEX.

1921.

January–May.

Abbott, W., Examination Prize Award, 10.—Presentation of Prize, 210.
Accounts for 1920, 6, 18–26.
Ackery, E. M., elected Graduate, 532.
Adam, A., elected Associate Member, 65.
Adamson, D., Remarks on Standardization of Testing Welds, 259.
Adamson, J., Decease, 4.
Aerial Ropeways for Loading of Ships, 70.
Agnew, P. G., Remarks on Limit-Gauging, 499.
Ahmed, M. S., *Paper* on Contact Pressures and Stresses, 365.
Allan, G., Memoir, 535.
Allcock, H., Associate Member transferred to Member, 66.
Allcock, H. J., elected Graduate, 202.
Allen, M., Decease, 4.
Allen, R. W., C.B.E., Remarks on Limit-Gauging, 503.
Allen, W. H., Past Vice-President, appointed a Member of the Council, 211.
Allen, W. M., Decease, 4.—Memoir, 535.
Alloys Research, 6.
Almond, W. C., elected Associate Member, 531.
Anderson, J. E., Commandership of Order of the British Empire, 3.
Anderson, J. H., Remarks on Mechanical Loading of Ships, 118.
Angles, J. W., elected Associate Member, 201.
Annual General Meeting, 1921, Business, 201.
Annual Report of the Council, 1.
April Meeting, 1921, Business, 469.
Archbutt, R. C., elected Associate Member, 65.
Arnold, N. H., elected Graduate, 66.
Ashbury, T., Decease, 4.—Memoir, 535.
Atherton, W. H., Remarks on Mechanical Loading of Ships, 146.
Atkinson, J. W., elected Associate Member, 531.
Attwood, J., Memoir, 536.

AUDITOR, Appointment, 213.

AUSTIN, P. E., elected Graduate, 202.

BAGNALL-WILD, Brig.-Gen. R. K., C.M.G., Remarks on Standardization of Testing Welds, 245.

BAILEY, R. W., Remarks on Purification of Boiler Feed-Water, 334, 342.

BAKER, H. W., elected Graduate, 362.

BALDWIN, C. K., Remarks on Mechanical Loading of Ships, 116.

BALE, M. P., Decease, 4.

BALL, Sir J. B., Decease, 4.—Memoir, 536.

BALL-HARDNESS TESTING-MACHINE, *Paper* by H. Moore, O.B.E., 51.

BAMBER, G. R., elected Graduate, 202.

BAMFORD, W., Associate Member transferred to Member, 203.

BANNISTER, A. H. G., elected Associate Member, 531.

BARKER, A. W. K., elected Associate Member, 531.

BARRACLOUGH, S. H. E., Knight Commandership of Order of the British Empire, 3.

BARRELL, K. C., elected Graduate, 470.

BATTEN, J. D., elected Graduate, 66.

BATY, J. E., Remarks on Limit Gauging, 519.

BEALE, A., elected Graduate, 470.

BEDSON, J. P., Remarks on Mechanical Loading of Ships, 134.

BEER, E. V., elected Graduate, 532.

BELT-CONVEYORS for loading of Ships, 81.

BENEVOLENT FUND, 17.—Remarks by the President thereon, 209.

BENNETT, A. E., Decease, 4.—Memoir, 537.

BENT, J. C., elected Associate Member, 361.

BENTHAM, C., Remarks on Mechanical Loading of Ships, 134.

BERRIDGE, H., Major, O.B.E., R.E., Companionship of Order of the Indian Empire, 3.

BERRIMAN, A. E., O.B.E., Remarks on Limit-Gauging, 500.

BERRY, T., Decease, 4.

BEXON, W. C., elected Member, 361.

BIDMEAD, P. W., elected Associate, 470.

BIGGIN, F., elected Member, 531.

BINNS, A., Remarks on Mechanical Loading of Ships, 110.

BIRCH, J., elected Member, 201.

BIRCH, T. elected Associate Member, 361.

BIRD, G., elected Graduate, 532.

BIRKS, N. A., elected Associate Member, 65.

BIRMINGHAM LOCAL BRANCH, Formation, 13.

BISHOP, MAJOR P., Remarks on Limit-Gauging, 502.

Blood, R. B., elected Graduate, 362.

Boiler Feed-Water, Degassing and Purification, 291. *See* Purification of Boiler Feed-Water.

Bonnyman, G. A., elected Graduate, 202.

Booth, T. A., elected Graduate, 202.

Bose, N. K., elected Associate Member, 201.

Bostock, F. J., Remarks on Limit-Gauging, 511.

Boswell, S., Remarks on Standardization of Testing Welds, 261.

Boxall, T. G. W., elected Graduate, 532.

Brackenbury, H. I., C.B.E., nominated for election as Member of Council, 64.—Elected Member of Council, 211.

Bradbury, A. W., elected Associate Member, 361.

Braham, J. E., elected Graduate, 532

Brame, J. S. S., Remarks on Purification of Boiler Feed-Water, 339.

Brearley, W. H., Decease, 4.

Brentnall, J. A., elected Associate Member, 65.

Bridgman, R. L., elected Graduate, 532.

Briggs, J. H., Decease, 4.

Brindley, H. S. B., Knight Commandership of Order of the British Empire, 3.—Decease, 4.

Brown, C., elected Associate Member, 361.

Brown, W., elected Associate Member, 469.

Browne, O. H., elected Associate Member, 201.

Browne, T. R., M.B.E., Decease, 4.—Memoir, 537.

Bryan Donkin Fund, Accounts, 25.—Regulations for Fifth Award, 27.

Bryant, R. H., elected Graduate, 362.

Bucka, P., elected Graduate, 532.

Bucket-Conveyor Shipping Plant, 75.

Bulleid, C. H., O.B.E., elected Member, 531.

Bunclark, F. T., elected Graduate, 470.

Burnet, H., elected Graduate, 470.

Burr, P. S., elected Associate Member, 531.

Butcher, J. J., Decease, 4.

Butterfield, H. V., elected Associate Member, 201.

Cadman, C. G., elected Associate, 202.

Calcutta and District Section, merged into Bengal Association of the Institution of Engineers (India), 13.

Caldwell, J., Major, R.E., Remarks on Standardization of Testing Welds, 256.

Candy, H. E. L., elected Associate Member, 65.

Cardwell, E., elected Graduate, 202.

Carnegie, D., Commandership of Order of the British Empire, 3.

Carosio, G., Associate Member transferred to Member, 203.

Carpenter, C. C., Commandership of Order of the British Empire, 3.

Carpenter, H , Remarks on Limit Gauging, 507.

Carr, R. S., elected Associate Member, 531.

Carrington, H., Remarks on Standardization of Testing Welds, 267 :— on Contact Pressures and Stresses, 454.

Cartwright, W., Jun., Decease, 4.

Casson, R., Decease, 4.

Cave-Browne-Cave, T. R., Wing-Com., Commandership of Order of the British Empire, 3.

Chakko, K. C., *Paper* on Contact Pressures and Stresses, 365.

Chandler, L. R., elected Graduate, 362.

Chapman, H. T., Appointment as Assistant Secretary, 5.

Charnock, G. F., Remarks on Limit Gauging, 518.

Chemical Industry, Society of, Joint Meeting, *Paper* on Degassing and Purification of Boiler Feed-Water, 289.

Cheshire, L. J., elected Graduate, 362.

Chew, W. E., elected Associate Member, 361.

Chorlton, A. E. L., C.B.E., nominated for election as Member of Council, 64.—Elected Member of Council, 211.

Civil Engineers' Registration Bill, 15.

Clark, B. F., elected Member, 65.

Clark, E. K., Lt.-Col., appointed Member of Council, 212.—Remarks on Limit Gauging, 509, 518.

Clark, J. d'A., elected Graduate, 470.

Clarke, A. G. R., elected Graduate, 202.

Clayton, J. A., Decease, 4.

Cleverly, A. W., elected Associate Member, 65.

Clynes, W., elected Graduate, 362.

Coade, L. G., elected Associate Member, 531.

Cobb, C. E., elected Associate Member, 361.

Codner, W. H., elected Associate Member, 201.

Coker, E. G., *Paper* on Contact Pressures and Stresses, 365.—Remarks thereon, 443, 455, 465.

Colebrook, C. M., elected Graduate, 362.

Coles, W. V., elected Graduate, 362.

Collins, J., elected Associate Member, 201.

Collot, H. G., elected Graduate, 532.

Contact Pressures and Stresses, *Paper* by E. G. Coker, K.C. Chakko, and M. S. Ahmed, 365.—Carus-Wilson's experiments, 366 ; results obtained, 368 ; stress difference along central vertical line, 379 ;

variation of thickness in ¼-inch plate, 384.—Possible errors and corrections of mechanical measurements: temperature variations, 385; errors of position, 386.—Possible errors in optical measurements, 389.—Stress distribution in blocks, 391.—Influence of contact stresses in testing of materials, 407.—Standard form of Dalby's test-piece, 424.

Discussion in London, 18 *March*, 1921.—Sankey, Capt. H. R., 434.—Hele-Shaw, H. S., 434.—Filon, L. N. G., 438.—Stromeyer, C. E., 441.—Luiggi, L., 441.—Coker, E. G., 443.

Discussion in Manchester, 21 *April*, 1921.—Day, C., 446.—Gibson, A. H., 446.—Stoney, G. G., 448.—Stromeyer, C. E., 450.—Herbert, E. G., 452.—Cook, G., 453.—Richardson, H., 454.—Carrington, H., 454.—Massey, L. F., 455.—Coker, E. G., 455.

Communications.—Fowler, Sir H., 459.—Hatfield, W. H., 460.—Scoble, W. A., 461.—Wingfield, C. H., 464.—Coker, E. G., 465.

CONVEYOR SHIPPING PLANT, 75.

COOK, G., Remarks on Contact Pressures and Stresses, 453.

COOKE, A., elected Graduate, 66.

COOKE, A. E. O., elected Graduate, 470.

COOKE, C. J. B., C.B.E., Decease, 4.—Memoir, 538.

COOPER, B. P., elected Associate Member, 361.

COOPER, T. W., Remarks on Limit Gauging, 505.

CORMACK, J. D., C.M.G., Commandership of Order of the British Empire, 3.

COSTE, J. H., Remarks on Purification of Boiler Feed-Water, 343.

COUNCIL, ANNUAL REPORT, 1.—No. of Members, etc., 1.—Curves showing growth from 1898, 2.—Royal Honours, 3.—Deceases, 4.—War Memorial.—Resignation of Secretary; appointments of Secretary and Staff, 5.—Financial statement, 6, 18–26.—Research Grants, 6.—Research Committees, 7.—By-laws *re* Membership applications, 9; admission of women, 10.—Examinations.—Informal Meetings, 10.—External technical training.—Portrait of Dr. Unwin.—Meetings and Papers, 11.—Thomas Hawksley Lecture.—Local Correspondents and Branches, 13.—Enlargement of Council, 13.—Lincoln Summer Meeting.—Graduates' Association, 14.—Civil Engineers' Registration Bill.—Watt Memorial in Birmingham, 15.—Proposed closing of Finsbury Technical College.—Representation on other Bodies, 16.—Benevolent Fund, 17.

Discussion.—Sankey, Capt. H. R., 203, 206, 207, 209.—Thompson, G. W., 205, 207, 209.—Pitt, P. S., 206, 207, 209.—Petter, E. W., 206.—Hele-Shaw, H. S., 207.—Spencer, H. B., 207.—Robinson, M. H., 208.—Drewitt, G. D., 209.—Report adopted, 209.

COUNCIL, Enlargement, 14.—Retiring List, and Nominations for 1921, 63. —Election, 210.—For 1921, 212.

COWAN, W., elected Associate Member, 469.

CRAIG, A., Commandership of Order of the British Empire, 3.

CRAMER, W., elected Graduate, 362.

CRANE, R., reappointed to audit Institution Accounts, 213.

CREWE, V., elected Member, 361.

CROFT, F. L., Decease, 4.—Memoir, 539.

CROMPTON, Col. R. E., C.B., Remarks on Limit Gauging, 507.

CROSBY, R., Remarks on Limit Gauging, 510.

CROSS, R. T. G., Decease, 4.—Memoir, 540.

CUMMING, J., elected Associate Member, 201.

CUTTING-TOOLS RESEARCH, 8.

DABELL, A. F., Associate Member transferred to Member, 470.

DAINTREE, T. E., Decease, 4.

DALGLIESH, D., elected Graduate, 202.

DANIELS, G. W., elected Associate Member, 361.

DANIELSEN, J. W., elected Member, 469.

DAS, A. N., elected Graduate, 470.

DAVEY, T. F., *Paper* on the Manufacture of British Association Screw-Thread Gauges, 191.—Presentation of Prize for Paper, 210.

DAVID, W. T., elected Associate Member, 532.

DAVIDSON, A. E., Lieut.-Col., D.S.O., R.E., nominated for election as Member of Council, 64.—Elected Member of Council, 211.

DAVIES, A. E. V., elected Associate Member, 201.

DAVIES, E. J., Decease, 4.

DAVIS, W. K., elected Associate Member, 361.

DAWSON, Sir A. T., Baronetcy, 3.

DAY, C., appointed Member of Council, 212.—Remarks on Contact Pressures and Stresses, 446.

DEACON, H. J., elected Graduate, 532.

DEAN, F. W. C., M.B.E., nominated for election as Member of Council, 64.

DECEASES of Members, etc., reported during 1920, 4.

DEGASSING AND PURIFICATION OF BOILER FEED-WATER, 291. *See* Purification of Boiler Feed-Water.

DEW, J. T., Associate Member transferred to Member, 470.

DEWRANCE, J., Knight Commandership of Order of the British Empire, 3. —Appointed Vice-President, 212.—*Lecture* to Graduates' Association on the Generation of Steam, 215.

DIMMOCK, A. L., elected Graduate, 532.

DIXON, D. M., elected Graduate, 202.

DOLBY, E. R., seconded reappointment of R. Crane as Auditor, 214.—Remarks on Standardization of Testing Welds, 251.
DONKIN, C. B., elected Associate Member, 532.
DONKIN FUND (BRYAN), Accounts, 25.—Regulations for Fifth Award, 27.
DONNAN, F. G., Remarks on Purification of Boiler Feed-Water, 338.
DOUGLASS, L., elected Graduate, 362.
DOWDEN, P. P., Lieut.-Col., R.A.S.C., elected Associate Member, 201.
DREWITT, G. D., Remarks on Annual Report, 209.
DRUMMOND, R. M., elected Associate Member, 65.
DUMAS, R., Remarks on Limit Gauging, 484.
DUMPERS for loading of Ships, 95.
DUNCANSON, J., elected Associate Member, 65.
DUNELL, H., O.B.E., elected Associate Member, 532.
DUNN, E. V., elected Graduate, 362.
DYSON, F., elected Associate Member, 532.

EASTON, R. S., Decease,4.—Memoir, 540.
EATOUGH, C., elected Graduate, 362.
EDGER, H. A., elected Associate Member, 201.
EDWARDS, C. A., elected Graduate, 362.
EDWARDS, W. S., Remarks on Mechanical Loading of Ships, 124.
ELDRIDGE, T. T., elected Graduate, 202.
ELECTION, Council, 210.—Members, etc., 65, 201, 361, 469, 531.
ELSTOB, F., Remarks on Standardization of Testing Welds, 275.
EMERTON, J. R., elected Member, 531.
EVANS, E. R., M.B.E., elected Associate Member, 469.
EXAMINATIONS, 10.—Award of Prizes, 10.—Presentation, 210.
EYEBOLTS, *Paper* on the Mechanical Qualities required, by R. T. Rolfe, 177.—Analyses of outside eyebolts, 178 ; effect of normalizing, 180.—Imitated service tests, 182.—Eyebolt specification, 187.—Additional results, 188.

FARMER, F. M., *Paper* on the Desirability of Standardization in the Testing of Welds, 225.—Remarks thereon, 287.
FARRAR, G. E., elected Associate Member, 201.
FEED-WATER, Degassing and Purification of Boiler, 291. *See* Purification of Boiler Feed-Water.
FELL, A. L. C., Commandership of Order of the British Empire, 3.
FELL, L. F. R., Lieut.-Col., D.S.O., O.B.E., R.A.F., elected Associate Member, 361.
FENNER, L. A., elected Associate Member, 532.
FILON, L. N. G., Remarks on Contact Pressures and Stresses, 438.

FINCH, H. J., elected Graduate, 362.
FINSBURY TECHNICAL COLLEGE, Proposed closing, 16.
FLETCHER, R. M., elected Associate Member, 469.
FORD, F. W., Appointment as Accountant, 5.
FOSTER, H. N., Lieut.-Col., C.B.E., R.A.S.C., Companionship of Order of St. Michael and St. George, 3.
FOWLER, Sir H., K.B.E., Remarks on Standardization of Testing Welds, 276 :—on Contact Pressures and Stresses, 434, 459.
FOX, W., Remarks on Mechanical Loading of Ships, 131, 137, 143, 146.
FRASER, D. S. D., elected Graduate, 362.

GARCKE, S. E., elected Member, 469.
GAUGES, Screw-Thread, 191. *See* Screw-Thread Gauges.
GAUGING, Limit, 473. *See* Limit Gauging.
GAULD, R. D., elected Graduate, 66.
GEDDES, C., Decease, 4.
GENERATION OF STEAM, *Lecture* to Graduates' Association by Sir J. Dewrance, K.B.E., 215.
GENÈVE, L. F. C. A., elected Associate Member, 469.
GIBB, Sir A., Brig.-Gen., C.B., Knight Grand Cross of Order of the British Empire, 3.
GIBB, M. S., Commandership of Order of the British Empire, 3.
GIBSON, A. H., Remarks on Contact Pressures and Stresses, 446.
GINDERS, E. M., Remarks on Standardization of Testing Welds, 268.
GLAISTER, E., elected Graduate, 362.
GLAZEBROOK, Sir R. T., Knight Commandership of Order of the Bath, 3 —Remarks on Limit Gauging, 473, 475, 508, 528.
GLEN, A. E., elected Graduate, 470.
GLEN, D. C., Decease, 4.—Memoir, 540.
GOACHER, W., elected Associate Member, 532.
GODDARD, H. P., Decease, 4.
GOMERSALL, J. W., Remarks on Mechanical Loading of Ships, 141.
GOODGER, A. H., Remarks on Standardization of Testing Welds, 270.
GOODMAN, H. F., elected Graduate, 202.
GOODMAN, R. T. W., elected Graduate, 470.
GOONEWARDENE, D. A., elected Associate Member, 201.
GOULD, A. J., elected Graduate, 470.
GOWER, G. P., elected Graduate, 202.
GRAB TRANSPORTERS, 97.
GRADUATES' ASSOCIATION, Awards for Papers, 14.
GRAHAM, M., Commandership of Order of the British Empire, 3.
GRANSDEN, C. L., Capt., R.A.O.C., I.O.M., elected Associate Member, 361.

Graves, J. G., *Lecture* on the World's Money System, 533.

Grayburn, R. C., elected Associate Member, 65

Green, F. M., Presentation of Prize for Paper, 210.

Gresley, H. N., Commandership of Order of the British Empire, 3.

Grieve, J. A. W., elected Graduate, 202.

Griffiths, A. W., elected Graduate, 532.

Griffiths, E., elected Associate Member, 469.

Griffiths, F. H., elected Member, 65.

Groundwater, S., Decease, 4.

Gueilikman, M., elected Associate Member, 361.

Gutteridge, H., elected Associate Member, 201.

Gwynne, N. G., Commandership of Order of the British Empire, 3.

Hadfield, Sir, R. A., Bart., nominated for re-election as Vice-President, 64.—Re-elected Vice-President, 211.

Hadfield (Sir Robert) Prize Fund, Grants, 6.—Accounts, 26.—Conditions of Award, 28.

Haigh, B. P., Award of Sir Robert Hadfield Prize, 6.—Remarks on Standardization of Testing Welds, 253.

Hall (T. Bernard) Prize Fund, Accounts, 26.—Conditions for Second Award, 30.

Hall-Brown, E., Decease, 4.

Hanford, R., elected Associate Member, 469.

Hardness Testing-Machine, *Paper* by H. Moore, O.B.E., 51.

Hardness Tests Research, 7.

Harris, H. E., elected Associate Member, 532.

Hartfree, G. B., elected Associate, 532.

Hartley, E., elected Associate Member, 469.

Hartnell, W., Decease, 4.—Memoir, 541.

Hastings, H. J., elected Associate Member, 469.

Hatfield, W. H., Remarks on Contact Pressures and Stresses, 460.

Hawksley Fund (Thomas), *Lecture* in 1920, 13.—Accounts, 25.

Hawksworth, J. W. M., elected Graduate, 532.

Hay, L. F., elected Associate Member, 65.

Haywood, C., elected Associate Member, 202.

Heaton, T. T., Remarks on Standardization of Testing Welds, 277.

Hedley, J. F., elected Associate Member, 202.

Hedley, R. C. H., elected Graduate, 532.

Heenan, H., Decease, 4.

Hele-Shaw, H. S., nominated for election as Vice-President, 64.—Elected Vice-President, 211.—Remarks on Annual Report, 207 :—

on Contact Pressures and Stresses, 434:—on World's Money System, 533.
HENDERSON, J. M., Remarks on Mechanical Loading of Ships, 149.
HENDERSON, T., Major, A.O.D., elected Member, 531.
HERBERT, E. G., Remarks on Contact Pressures and Stresses, 452.
HEYWOOD, W. J., elected Graduate, 362.
HIBBERD, F. C., Remarks on Standardization of Testing Welds, 278.
HIGSON, J., Decease, 4.—Memoir, 541.
HILBORN, F. A., Capt., R.E., elected Associate, 470.
HINCHLEY, J. W., Remarks on Purification of Boiler Feed-Water, 331.
HINDS, C. R., elected Graduate, 470.
HOBSON, J. W., Associate Member transferred to Member, 363.
HOCKLEY, H. R., elected Graduate, 202.
HOEY, G. McC., elected Associate, 532.
HOLBEIN, A. M., elected Graduate, 362.
HOLLANDS, H. W., elected Graduate, 202.
HONOURS conferred by H.M. The King, 3.
HOPKINSON, C., Decease, 4.
HOPKINSON, E., M.P., Past-President, appointed a Member of the Council, 211.
HOYLE, J. R., Past-Vice-President, appointed a Member of the Council, 211.
HUDSON, A., elected Graduate, 470.
HUDSON, R. J. H., elected Associate Member, 361.
HUGHES, G., Commandership of Order of the British Empire, 3.
HUGHES, H. M., elected Graduate, 362.
HUNTER, J., Decease, 4.—Memoir, 542.
HURLEY, P., elected Graduate, 532.
HUSK, A. C., elected Graduate, 362.

I'ANSON, H. C., Capt., R.A.S.C., elected Member, 531.
IGNATIEFF, A., elected Member, 361.
INFORMAL MEETINGS, 10.
IRONSIDE, Sir W., Decease, 4.
ISLIP, P. C., elected Graduate, 202.

JACKSON, P. G., Remarks on Purification of Boiler Feed-Water, 346.
JACKSON, W. M., Remarks on Standardization of Testing Welds, 268.
JANUARY MEETING, 1921, Business, 63.
JARRED, H. A., elected Associate Member, 362.
JENKINS, C. E., elected Associate Member, 202.

Jenkins, D., elected Member, 531.

Jennings, H. A., elected Graduate, 202.

Jensen, A. E., elected Associate Member, 202.

Johnson, P. H., Lieut.-Col., D.S.O., Commandership of Order of the British Empire, 3.

Johnson, R. S., Remarks on Standardization of Testing Welds, 247.

Jones, A. W., elected Associate Member, 469.

Jones, E. H., Remarks on Standardization of Testing Welds, 280.

Jones, E. L., elected Graduate, 362.

Jones, J. C., elected Graduate, 532.

Judd, C. H., elected Graduate, 202.

Keal, H. H., elected Associate Member, 362.

Keep, H. S., elected Graduate, 202.

Keevill, R. G., elected Associate Member, 65.

Kemish, H., elected Member, 531.

Kerridge, W., elected Graduate, 362.

Kestner, P., *Paper* on Degassing and Purification of Boiler Feed-Water, 291.—Remarks thereon, 342, 351.

Kingston-McCloughry, E. J., Capt., D.S.O., D.F.C., elected Graduate, 66.

Kininmonth, C. P., Remarks on Mechanical Loading of Ships, 142.

Kirkaldy, J., Decease, 4.

Kirke, P. St. G., elected Associate Member, 532.

Knight, R. D., elected Graduate, 202.

Knowles, T. W. G., elected Graduate, 362.

Lang, E. F., Remarks on Standardization of Testing Welds, 265.

Larke, W. J., Commandership of Order of the British Empire, 3.

Lawrence, M. R., Remarks on Limit-Gauging, 501.

Leech, W., elected Member, 469.

Leeds Local Branch, Formation, 13.

Legros, L. A., O.B.E., nominated for election as Member of Council, 64. Appointed Member of Council, 212.

Le Maistre, C., Remarks on Limit-Gauging, 501.

Le Masurier, J., Commandership of Order of the British Empire, 3.

Leonard, L. D., elected Associate Member, 202.

L'Estrange, A. H. C., Decease, 4.—Memoir, 542.

Lewis, E. H., elected Graduate, 66.

Library Donations, 11, 31–50.

Limit Gauging, *Note* by Sir R. T. Glazebrook, K.C.B., 473.—Basis for

Standardization.—Unilateral and Bilateral Systems.—Systems of Limits, 473.—Steps and Ranges.—Limit Lines.—Illustrations of Systems of Limits, 474.

Discussion in London, 22 *April*, 1921.—Glazebrook, Sir R. T., 475, 508.—Sankey, Capt. H. R., 475, 481.—Taylor, W., 481. —Dumas, R., 484.—Thomson, H. J., 486.—Agnew, P. G., 499. —Berriman, A. E., 500.—Lawrence, M. R., 501.—Le Maistre, C., 501.—Bishop, Major P., 502.—Allen, R. W., 503.—Cooper, T. W., 505.—Ross, Major A. A., 505.—Crompton, Col. R. E., 507.—Carpenter, H., 507.

Discussion in Leeds, 2 *May*, 1921.—Clark, Lt.-Col. E. K., 509.—Thomson, H. J., 510.—Crosby, R., 510.—Bostock, F. J., 510.—Watson, Major F. L., 512.—Murray, G. L., 514.—Charnock, G. F., 519.

Communications.—Baty, J. E., 519.—Remington, A. A., 523.—Watson, G. W., 527.—Glazebrook, Sir R. T., 528.

LINDSAY, W. G., elected Graduate, 202.

LINGARD, A., elected Associate Member, 532.

LIVENS, F. H., nominated for election as Member of Council, 65.—Appointed Member of Council, 212.

LLOYD, W. F., elected Graduate, 470.

LOADING OF SHIPS, Mechanical, 67.

LOBNITZ, F., Knight Commandership of Order of the British Empire, 3.

LOCAL BRANCHES, 13.—CORRESPONDENTS, 13.

LONDON, H. M. A., elected Associate Member, 202.

LONGRIDGE, M., Commandership of Order of the British Empire, 3.—Past-President, appointed a Member of the Council, 211.

LOWDELL, S. J., Major, R.A.O.C., elected Associate Member, 65.

LUIGGI, L., Remarks on Contact Pressures and Stresses, 441.

LYALL, A., Jun., elected Graduate, 362.

LYON, G., elected Graduate, 532.

MCCALLUM, E. A., Decease, 4.

MCFADYEN, A., Associate Member transferred to Member, 363.

MCINNES, O. H., elected Member, 65.

MACIVOR, D. T., elected Associate Member, 532.

MACKIE, T. D., Col., C.M.G., O.B.E., Associate Member transferred to Member, 66.

MCLAREN, Sir J., K.B.E., Decease, 4.—Memoir, 543.

MACLEAN, J., elected Associate Member, 532.

MCMURRAY, R., elected Member, 65.

McNaughton, A., elected Associate Member, 65

McQuade, W., M.B.E., elected Associate Member, 362,

Mair-Rumley, J. G., Decease, 4.

Maitland, C., Decease, 4.—Memoir, 543.

Manchée, H. V., elected Graduate, 532.

Manchester Local Branch, Formation, 13.

Mansell, A. G., elected Graduate, 202.

Mansfield, A., Knight Commandership of Order of the British Empire, 3.

March Meetings, 1921, Business, 289, 361.

Marks, E. C. R., appointed Member of Council, 212.

Marris, R. W. H., Companionship of Order of the Indian Empire, 3.

Marshall, R., elected Member, 65.

Maryon, J. F., elected Member, 65.

Massey, L. F., Remarks on Contact Pressures and Stresses, 455.

Mather, R. A., elected Associate Member, 532.

Mather, The Rt. Hon. Sir W., P.C., LL.D., Decease, 4.—Memoir, 544.

Maw, W. H., Past-President, appointed a Member of the Council, 211.

Maxwell, D. W. F., Decease, 4.

May Meeting, 1921, Business, 531.

Meadows, F. C., elected Associate Member, 362.

Mechanical Loading of Ships, *Paper* by H. J. Smith, 67.—Primary transporters.—Competition, 68.—Machinery *v.* Coolie.—Successful methods, 69.—Formula, 70.—Aerial ropeways: Sebabna Mines. 70; ropeway, 72; terminal and tension stations, 73; storage bunkers, 74; bucket conveyor, 75; structure, 77; power and drive, 78; loading steamers, 80.—Belt-conveyors, 81; life and capacity, 82; feed-hoppers, 85; power required, 87; structure, pulleys, and idlers, 88; skirt-boards, 90; Durban conveyor, 91.—Wagon-dumpers: comparisons, 93; side-tipping dumper, 95; operation, 96.—Grab transporters, 97; types; Han-Yeh-Ping transporter, 98; structure, 99.—Chinese steel, 100.—Formula for belt-conveyors, 102; for bucket-conveyors, 105.

Discussion in London, 21 *Jan.* 1921.—Parker, F. T., 110.—Sankey, Capt. H. R., 110.—Binns, A., 110.—Baldwin, C. K., 116.—Anderson, J. H., 118.—Mitchell, F. G., 123.—Edwards, W. S., 124.—Parker, F. T., 127.

Discussion in Manchester, 27 *Jan.* 1921.—Parker, F. T., 129.—Fox, W., 131.—Bedson, J. P., 134.—Bentham, C., 134.—Smith, W. G., 139.—Gomersall, J. W., 141.—Kininmonth, C. P., 142.—Parker, F. T., 144.—Fox, W., 146.

Communications.—Atherton, W. H., 146.—Henderson, J. M., 149.—Mitchell, F. G., 151.—Patchell, W. H., 154.—Ritchie, T. M., 154.—Smart, A., 156.—Spence, W. L., 159.—Steinheil, Baron G., 161.—Wright, A. R., 162.—Zimmer, G. F., 163.—Parker, F. T., 164.

Meeting, Joint, with Society of Chemical Industry, 289.

Meetings, 1921, *London*, January, 63.—Annual General, 201.—March, 289, 361.—April, 469.—May, 531.—*Leeds*, 471.—*Manchester*, 66, 214, 259, 363, 446.

Memoirs of Members, etc., recently deceased, 535.

Memorial, War, 5.—Unveiling and Dedication, 197.

Metcalf, B. L., elected Graduate, 202.

Metcalf, H. K., elected Graduate, 202.

Metcalfe, J., Decease, 4.

Millar, R. H., elected Graduate, 532.

Miller, J. F. X., Capt., R.A.O.C., elected Associate Member, 469.

Mills, S. E., elected Associate Member, 469.

Mills, W., nominated for election as Member of Council, 65.—Remarks on Standardization of Testing Welds, 258.

Mitchell, A. M., elected Graduate, 532.

Mitchell, F. G., Remarks on Mechanical Loading of Ships, 123, 151.

Mitchell, R. J., elected Associate Member, 469.

Money System of the World, *Lecture* by J. G. Graves, 533.

Montagu, Lord, Knight Commandership of Order of the Indian Empire, 3.

Montgomrey, J. E., Appointment as Assistant Secretary (Tech.), 5.—Elected Associate Member, 65.

Moon, H. P., elected Associate Member, 202.

Moore, H., O.B.E., Award of Sir Robert Hadfield Prize, 6.—*Paper* on a small Ball-Hardness Testing-Machine, 51.—Presentation of Sir Robert Hadfield Prize, 210.

Morgan, W., elected Associate Member, 362.

Morris, W. H., Examination Prize Award, 10.—Presentation of Prize, 210.

Morton, W. A., elected Associate Member, 362.

Mowat, M., Brig.-Gen., Commandership of Order of the British Empire, 3.—Appointed Secretary, 5.

Moyes, T. F., elected Graduate, 362.

Munro, W. T., elected Graduate, 202.

Muntz, Sir G. A., nominated for re-election as Member of Council, 64.—Re-elected Member of Council, 211.—Appointed Vice-President, 212.

Murray, G. L., Remarks on Limit Gauging, 514.

Musgrave, J., elected Associate Member, 202.

Nell, L., Associate Member transferred to Member, 470.

Newling, W. P., elected Associate Member, 202.

Nicholls, E. G., elected Associate Member, 65.

Nielsen, H. L. R., elected Member, 469.

Noyes, E., Decease, 4.

Oakes, R., Lt.-Col., R.E., Commandership of Order of the British Empire, 3.

Ogden, H., Remarks on Standardization of Testing Welds, 281.

Ogilvie, A., C.B.E., elected Member, 65.

Oil-Engines Nomenclature Committee, 9.

Oram, Sir H. J., Eng. Vice-Adm., K.C.B., Retirement from Council, 64

Ord, T. C., elected Graduate, 470.

Ormandy, W. R., Remarks on Purification of Boiler Feed-Water, 340.

Ormesher, E., elected Member, 361.

Owen, W., elected Graduate, 66.

Oxbrow, J. F., elected Associate Member, 65.

Pacey, S. O., Associate Member transferred to Member, 203.

Page, A. C., Examination Prize Award, 10.—Presentation of Prize, 210.

Panton, S. J. A., elected Graduate, 202.

Parez, W. T., Eng. Com., R.N., elected Member, 531.

Parker, F. T., Remarks on Mechanical Loading of Ships, 110, 127, 129, 144, 164.

Patchell, W. H., Remarks on Mechanical Loading of Ships, 154.—Appointed Vice-President, 212.—Remarks on Standardization of Testing Welds, 245, 258, 274 :—on Purification of Boiler Feed-Water, 342:—on World's Money System, 533.

Patterson, A., Decease, 4.

Paul, D., Lt.-Col., C.M.G., C.B.E., R.A.O.C., Companionship of Order of the Bath, 3.

Payne, R., Memoir, 545.

Pearson, R. J. A., Remarks on Standardization of Testing Welds, 282.

Peck, H. A., Capt., R.E., elected Associate Member, 469.

Peck, J. F., elected Graduate, 202.

Pemberton, S. T., elected Associate, 470.

Pendred, L. St. L., nominated for election as Member of Council, 64.—Elected Member of Council, 211.

Penn, A. E., Capt., R.A.F., elected Member, 531.

Petavel, J. E., Knight Commandership of Order of the British Empire, 3.

Peters, H., elected Graduate, 362.

PETRIE, P. T., elected Associate Member, 532.

PETTER, E. W., nominated for election as Member of Council, 65.—Remarks on Annual Report, 206.—Appointed Member of Council, 212.

PILE, J. E., elected Associate Member, 65.

PILKINGTON, P., elected Graduate, 202.

PINCHBECK, A. S., elected Graduate, 66.

PISTON-RINGS RESEARCH, 8.

PITT, G. A., elected Graduate, 202.

PITT, P. S., Remarks on Annual Report, 206, 207, 209.

PITT, W., Decease, 63.

PLEYDELL-NOTT, J. G. L., Major, D.S.O., R.A.S.C., elected Associate Member, 362.

PLOWRIGHT, J. T., Decease, 4.—Memoir, 546.

PLUNKET, P. A., elected Graduate, 470.

PONTET, H., elected Associate Member, 202.

POOLE, J. W., elected Associate Member, 65.

POOLEY, F. H., Capt., elected Associate Member, 66.

POPE, Sir W., K.B.E., Remarks on Purification of Boiler Feed-Water, 330.

PORTRAIT OF DR. W. C. UNWIN, 11.

POTTS, S. C., Major, R.E., elected Associate Member, 362.

POWNEY, W. E. F., Remarks on Purification of Boiler Feed-Water, 343.

PRESCOTT, W. H., M.P., Commandership of Order of the British Empire, 3.

PRESSURES AND STRESSES, 365. *See* Contact Pressures and Stresses.

PRESTON, J. S., elected Graduate, 202.

PRICE, J. V., elected Graduate, 362.

PRIOR, U. J., elected Graduate, 203.

PURIFICATION OF BOILER FEED-WATER, *Paper* by P. Kestner, 291.—Purification at high temperature, 292 ; increase of speed of reaction ; diminution of viscosity, 293.—Continuous blow-down, 295 ; position of blow-down ; proportions, 300.—Central stations using distilled water, 302.—Causes of Corrosion, 305.—Oxygen in solution in feed, 309 ; method of obtaining oxygen content, 312.—Removal of gases by physical methods, 314 ; thermal and mechanical removal, 317 ; vacuum appliances, 318 ; chemical removal, 319 ; Kestner apparatus, 323.

Joint Discussion with Society of Chemical Industry.—Sankey, Capt. H. R., 330.—Pope, Sir W., 330.—Hinchley, J. W., 331.—Spyer, A., 332.—Bailey, R. W., 334.—Donnan, F. G., 338.—Braine, J. S. S., 339.—Ormandy, W. R., 340.—Patchell, W. H., 342.—Kestner, P., 342.

Communications.—Bailey, R. W., 342.—Coste, J. H., and

Powney, W. E. F., 343.—Jackson, P. G., 346.—Riviere, P. L., 347. —Kestner, P., 351.

Purnell, H. G., elected Graduate, 532.

Pyne, F. D., Major, R.E., Decease, 4.

Randerson, G., elected Graduate, 362.

Raven, Sir V. L., K.B.E., appointed Vice-President, 212.

Rawlings, P. T., Capt. R.A.F., Decease, 4.—Memoir, 546.

Rayden, R. G., elected Graduate, 203.

Reavell, W., nominated for re-election as Member of Council, 64.—Re-elected Member of Council, 211.

Redfern, C. J., Associate Member transferred to Member, 363.

Reeve, W. A., elected Associate Member, 470.

Refrigeration Research, 8.

Reid, R. W., Commandership of Order of the British Empire, 3.—Associate Member transferred to Member, 66.

Reid, W. A., elected Graduate, 470.

Remington, A. A., Remarks on Limit-Gauging, 523.

Renfrew, J. McK., elected Associate Member, 470.

Renton, G. A., elected Associate Member, 470.

Renton, G. F., elected Graduate, 470.

Report of Council, Annual, 1.

Research.—Grants, 6 :—Alloys ; Wire-Ropes ; Steam Nozzles ; Hardness, 7 ; Piston Rings ; Cutting Tools ; Refrigeration, 8.

Revill, J. J. C., Capt., R.E., elected Associate Member, 66.

Rich, T. A., Remarks on Standardization of Testing Welds, 273.

Richards, T. H., elected Associate Member, 202.

Richardson, D., Capt., R.A.F., Remarks on Standardization of Testing Welds, 251.

Richardson, H., Remarks on Contact Pressures and Stresses, 454.

Richardson, J., Decease, 4.

Richardson, P., Capt., R.E., elected Associate Member, 470.

Richardson, T. B., elected Associate Member, 362.

Ridley, C. O., O.B.E., nominated for election as Member of Council, 65.

Ritchie, J., elected Graduate, 203.

Ritchie, T. M., Remarks on Mechanical Loading of Ships, 154.

Riviere, P. L., Remarks on Purification of Boiler Feed-Water, 347.

Roberts, D. E., nominated for election as Member of Council, 64.—Appointed Member of Council, 212.

Roberts, G. H., C.B.E., Remarks on Standardization of Testing Welds, 283.

ROBERTS, T., Decease. 4.
ROBERTSON, D. A., elected Graduate, 362.
ROBERTSON, H. J., Capt., M.C., R.A.S.C., elected Associate Member, 470.
ROBERTSON, J. F., Associate Member transferred to Member, 470.
ROBINS, G. M., Decease, 4.
ROBINSON, G. H., elected Associate Member, 202.
ROBINSON, J. G., Commandership of Order of the British Empire, 3.
ROBINSON, M. H., Past Vice-President, appointed a Member of the Council, 211.—Remarks on Annual Report, 208.
ROGERSON, A. C., Commandership of Order of the British Empire, 3.
ROGERSON, J., Decease, 4.
ROLFE, R. T., *Paper* on the Mechanical Qualities required in Eyebolts, 177.
ROLLO, G., Brig.-Gen., D.S.O., Companionship of Order of St. Michael and St. George, 3.
RONALD, J., M.B.E., elected Associate Member, 362.
RONS, R. F., elected Associate Member, 66.
ROPEWAYS, Aerial, for Loading of Ships, 70.
ROSCOE, H. J., elected Associate Member, 470.
ROSE, S., elected Associate Member, 202.
ROSS, Major A. A., O.B.E., Remarks on Limit Gauging, 505.
ROSS, A. J. C., Commandership of Order of the British Empire, 3.
ROSS, F. G., Decease, 4. —Memoir, 547.
ROSS, H. H., elected Graduate, 362.
RUNDALL, C. F., Lt.-Col., D.S.O., R.E., Companionship of Order of St. Michael and St. George, 3.
RYVES, F. D. M., elected Graduate, 203.

SADLER, R. W., elected Associate Member, 532.
SANKEY, H. R., Capt., C.B., R.E., ret., Commandership of Order of the British Empire 3.—Remarks on Decease of W. Pitt, 63.—Nominated for re-election as President, 64.—Remarks on Mechanical Loading of Ships, 110, 128 : —at Unveiling and Dedication of War Memorial, 197 :—on Annual Report, 203–9 :—on Benevolent Fund, 209.—Re-elected President, 210.—Remarks on Standardization of Testing Welds, 245, 256 :—on Joint Meeting with Society of Chemical Industry, 289 :—on Purification of Boiler Feed-Water, 330 :—on Contact Pressures and Stresses, 434 :—on Limit Gauging, 475, 481.
SCOBLE, W. A., Remarks on Contact Pressures and Stresses, 461.
SCOTLAND, L. J., elected Graduate, 532.

SCOTT, H. R., elected Graduate, 203.

SCOTT, J., Decease, 4.

SCREW-THREAD GAUGES, *Paper* by T. F. Davey, 191.—Tolerance, 191.—Methods and apparatus used.—Compensation and correction for errors.—Cutting tools.—Taps, 192.—Lapping, 194.—Heat treatment, 195.—Correction of errors, 196.

SECRETARYSHIP, Resignation of E. Worthington, 5.—Appointment of Brig.-Gen. M. Mowat, 5.

SETHNA, R. M., elected Associate Member, 362.

SHEPHARD, G. A., elected Graduate, 362.

SHIPS, Mechanical Loading, 67. *See* Mechanical Loading of Ships.

SHIRTLIFF, E. M., elected Graduate, 362.

SIMMONDS, S. H., elected Graduate, 362.

SIMS, G. A., Capt R.A.S.C., elected Associate Member, 470.

SINGLETON, A. B., elected Associate Member, 66.

SIR ROBERT HADFIELD PRIZE FUND, Grants, 6.—Accounts, 26.—Conditions of Award, 28.

SMART, A., Remarks on Mechanical Loading of Ships, 156.

SMITH, A. J., Associate Member transferred to Member, 363.

SMITH, D. B., elected Graduate, 470.

SMITH, F. L., elected Associate Member, 66.

SMITH, H., M.B.E., Memoir, 547.

SMITH, H. A., elected Graduate, 362.

SMITH, M. H., moved reappointment of R. Crane as Auditor, 213.

SMITH, H. J., *Paper* on the Mechanical Loading of Ships, 67.

SMITH, H. R., Associate Member transferred to Member, 363.

SMITH, W. G., Remarks on Mechanical Loading of Ships, 139.

SMITZ, W. B., elected Graduate, 470.

SOCIETY OF CHEMICAL INDUSTRY, Joint Meeting, *Paper* on Degassing and Purification of Boiler Feed-Water, 289.

SOUZA, M. C. de, elected Graduate, 532.

SPARKES, W. J., elected Graduate, 203.

SPENCE, W. L., Remarks on Mechanical Loading of Ships, 159.

SPENCER, A. J., Associate Member transferred to Member, 203.

SPENCER, C. A., elected Graduate, 203.

SPENCER, H. B., Remarks on Annual Report, 207.

SPYER, A., Remarks on Purification of Boiler Feed-Water, 332.

STAFF, S. H., elected Graduate, 532.

STAMER, A. C., Commandership of Order of the British Empire, 3.

STAMFORD, A. R., Major, R.A.O.C., elected Member, 531.

STANDARDIZATION OF TESTING WELDS, *Paper* by F. M. Farmer, 225.—Necessity, 226.—Fundamental basis.—Kinds of Standards : Shop, 227; Commercial; Research, 228.—Numerical evaluation of welds, 229.—Standard procedure in mechanical tests, 230; tensile, 231; bending, 232; fatigue, 235; machine for testing, 237.—No. of specimens that should be tested, 240.—Elongation data, tests, etc., in tensile tests, 241.—Standard stress value in fatigue, 242.—Inspection and tests of welds in structures, 244.

Discussion in London, 18 *Feb.*, 1921.—Patchell, W. H., 245, 258.—Sankey, Capt. H. R., 245, 256.—Bagnall-Wild, Brig.-Gen. R. K., 245.—Johnson, R. S., 247.—Dolby, E. R., 251.—Richardson, Capt. D., 251.—Haigh, B. P., 253.—Stanton, T. E., 255.—Caldwell, Major J., 256.—Mills, W., 258.

Discussion in Manchester, 24 *Feb.*, 1921.—Adamson, D., 259.—Stromeyer, C. E., 261, 263.—Boswell, S., 261.—Lang, E. F., 265.—Carrington, H., 267.—Ginders, E. M., 268.—Jackson, W. M., 268.—Goodger, A. H., 270.—Rich, T. A., 273.—Patchell, W. H., 274.

Communications.—Elstob, F., 275.—Fowler, Sir H., 276.—Heaton, T. T., 277.—Hibberd, F. C., 278.—Jones, E. H., 280.—Ogden, H., 281.—Pearson, R. J. A., 282.—Roberts, G. H., 283.—Wingfield, C. H., 286.—Farmer, F. M., 287.

STANTON, T. E., Commandership of Order of the British Empire, 3.—Nominated for election as Member of Council, 65.—Elected Member of Council, 211.—Remarks on Standardization of Testing Welds, 255.

STARLEY PREMIUM FUND, Accounts, 24.

STEAM, GENERATION OF, *Lecture* to Graduates' Association by Sir J. Dewrance, K.B.E., 215.—Output of coal, 215.—Absorption of heat by water, 216.—Corrosion, 217; effect of magnesium chloride, 218; effect of soda, 219.—Air corrosion, 221.—Effect of oil, 222; Plumbago instead of oil for lubrication, 223.

STEAM-NOZZLES RESEARCH, 7.

STEINHEIL, Baron G., Remarks on Mechanical Loading of Ships, 161.

STILES, H., elected Associate Member, 66.

STOCK, A. R., Appointment as Librarian, 5.

STONEY, G. G., Remarks on Contact Pressures and Stresses, 448.

STRESSES, 365. *See* Contact Pressures and Stresses.

STROMEYER, C. E., O.B.E., Remarks on Standardization of Testing Welds, 261, 263:—on Contact Pressures and Stresses, 441, 450.

STUART, M. D. G., elected Graduate, 203.

STUDENT VISITORS, 15.

SUCKAN, C. A., elected Associate Member, 362.

SUMMER MEETING, Lincoln, 14.

SWAN, A., elected Associate Member, 66.
SWAN, P., elected Member, 65.
SYMONDS, J. C., Major, R.A.S.C., elected Associate Member, 202.

TAFFS, C. W. J., elected Associate Member, 202.
TAMPLIN, G. R., elected Graduate, 532.
TANGYE, G., Decease, 5.—Memoir, 548.
TAYLOR, W., O.B.E., Remarks on Limit Gauging, 481.
TAYLOR, W. H., Decease, 5.
TESTING-MACHINE, Ball-Hardness, *Paper* by H. Moore, O.B.E., 51.
THOMAS HAWKSLEY FUND, *Lecture* in 1920, 13.—Accounts, 25.
THOMPSON, C., elected Graduate, 203.
THOMPSON, G. W., Remarks on Annual Report, 205, 207, 209.
THOMPSON, J., Associate Member transferred to Member, 470.
THOMSON, H. J., Remarks on Limit Gauging, 486, 510.
THORNLEY, G., Decease, 5.
THORP, H., elected Associate Member, 362.
TITREN, G. E. de K., Associate Member transferred to Member, 203.
TRANSFERENCES of Associate Members to Members, 66, 203, 363, 470, 533.
TRANSPORTERS for loading of Ships, 97.
TRAVIS, H., Commandership of Order of the British Empire, 3.
TRIGLE, S. E., elected Associate Member, 202.
TROST, H. R., elected Associate Member, 532.
TULIP, W., Decease, 5.
TWINCH, W., elected Associate Member, 362.

UNWIN, W. C., Portrait, 11.—Past-President, appointed a Member of the Council, 211.

VAUGHAN, P. B., elected Graduate, 203.
VENNING, S. E., elected Associate Member, 66.
VICKERY, F. W., O.B.E., elected Member, 65.

WADAMS, S. J., elected Associate Member, 202.
WADE, E. D., Decease, 5.
WAGON-DUMPERS, 93.
WALKEM, G. A., Associate Member transferred to Member, 203.
WALL, L. A., elected Graduate, 66.
WALTER, R. C., elected Associate Member, 470.
WAR MEMORIAL, 5.—Unveiling and Dedication, 197.
WARD, W., elected Associate Member, 66.

WATER, Degassing and Purification, 291. *See* Purification of Boiler Feed-Water.

WATER ARBITRATION PRIZE FUND, Accounts, 24.—Regulations for Seventh Award, 27.

WATERS, H. R., elected Graduate, 532.

WATSON, Major F. L., Remarks on Limit Gauging, 512.

WATSON, G. W., Remarks on Limit Gauging, 527.

WATSON, R. S., Decease, 5.—Memoir, 549.

WATT MEMORIAL, 15.

WATTS, H. W., Capt., R.E., Associate Member transferred to Member, 203.

WAYTE, J. B., Decease, 5.

WEBB, H. A., Associate Member transferred to Member, 533.

WEBB-BOWEN, H. E., Col., D.S.O., R.E., Companionship of Order of St. Michael and St. George, 3.

WEIR, Lord, P. C., Retirement from Council, 64.

WELDS, Standardization of Testing, 225. *See* Standardization of Testing Welds.

WESTMINSTER, THE DEAN OF, dedicated War Memorial, 199.

WHITEHEAD, R. W., elected Associate Member, 470.

WHITEHOUSE, H. E., elected Graduate, 66.

WHYTE, D., elected Graduate, 203.

WILCOX, J. G., Decease, 5.—Memoir, 549.

WILD, W. R., elected Associate Member, 532.

WILLANS PREMIUM FUND, Accounts, 24.

WILLCOX, C. W., elected Associate Member, 202.

WILLIAMSON, E., Associate Member transferred to Member, 533.

WILSON, T. M., elected Associate Member, 362.

WINDER, B. W., Decease, 5.—Memoir, 549.

WINDLE, S. R., elected Member, 531.

WINGFIELD, C. H., Remarks on Standardization of Testing Welds, 286:—on Contact Pressures and Stresses, 464.

WIRE-ROPES RESEARCH, 7.

WITHERS, G. M., M.B.E., elected Associate Member, 532.

WOMEN CANDIDATES for Membership, 10.

WOOD, Sir L., Bart., Decease, 5.—Memoir, 550.

WOODING, J., elected Graduate, 203.

WORLD'S MONEY SYSTEM, *Lecture* by J. G. Graves, 533.

WORSDELL, W., Decease, 5.

WORTHINGTON, E., Resignation of Secretaryship, 5.

WRIGHT, A. R., Remarks on Mechanical Loading of Ships, 162.

WRIGHT, H., Decease, 5.—Memoir, 551.

WRIGHT, J. R., Col., Baronetcy, 3.

Wright, P. A., elected Graduate, 203.
Wyvill, F. C., Decease, 5.

Young, F. W., Capt., C.B.E., Knight Commandership of Order of the British Empire, 3.

Zimmer, G. F., Remarks on Mechanical Loading of Ships, 163.

BALL-HARDNESS TESTING-MACHINE

Fig. 2.
Small Ball-hardness Testing-Machine.
Capacity 100 kg. shown with ball of 1 mm. diam., and load of 10 kg.

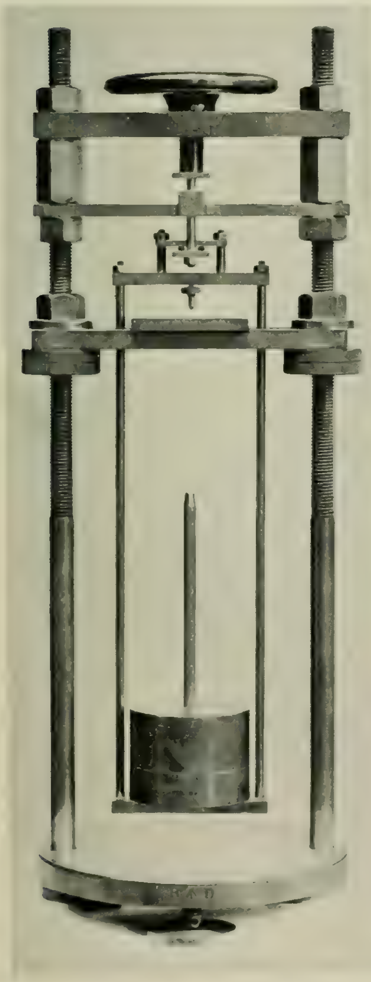


Fig. 3. *Table of Machine, with fitting for carrying on a mandril the middle portion of a small-arm cartridge-case.*

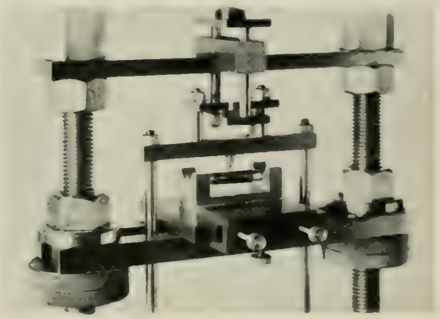
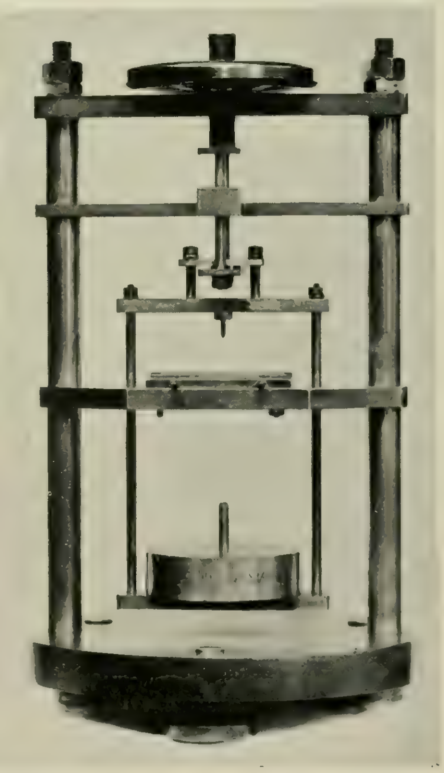
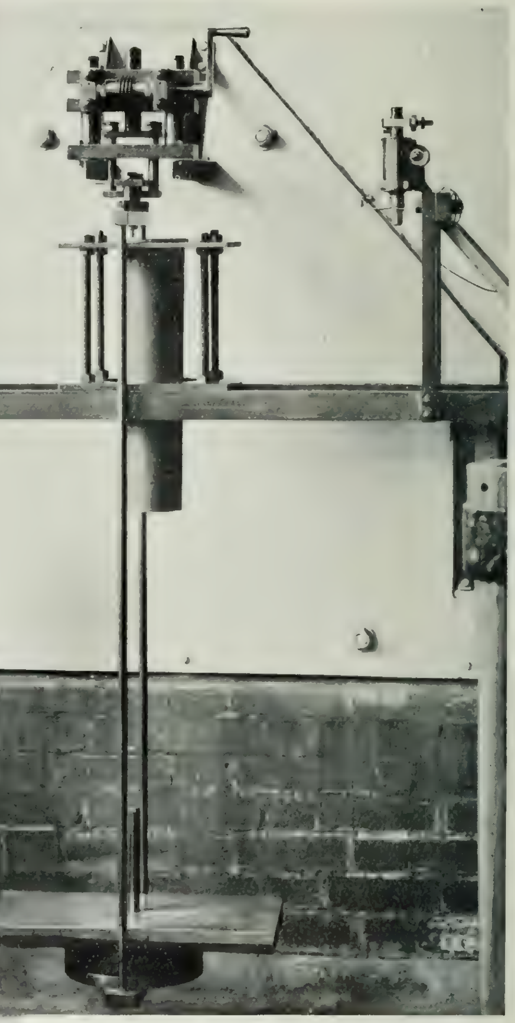


Fig. 4. *Machine designed for testing small-arm cartridge-cases.*
Diam. of ball, 0·8 mm. Load, 6·4 kg.



BALL-HARDNESS TESTING-MACHINE.

Fig. 5.
250 kg. Machine designed for testing Q.F. cartridge-cases and other large objects, with microscope attached.



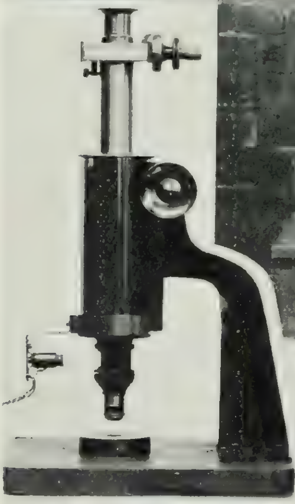


Fig. 6. *Microscope fitted with lamp, vertical illuminator and filar micrometer eye-piece, for measuring small impressions.*

Fig. 7. *Axial section through a broken tensile test-piece. The strain-hardening has been explored by means of the impressions shown, made with a ball of 1 mm. diam. and a load of 30 kg.*

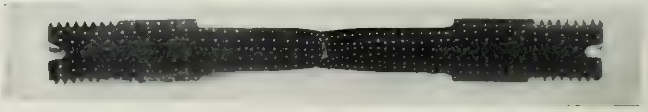


Fig. 1. *Grab Transporter, for Unloading Colliers and Bunkering Battleships.*

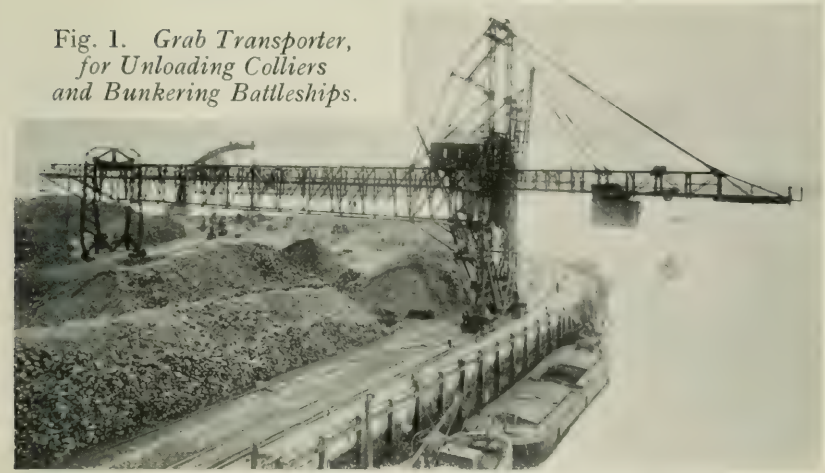


Fig. 2. *Coaling Transporter, Port Natal.*

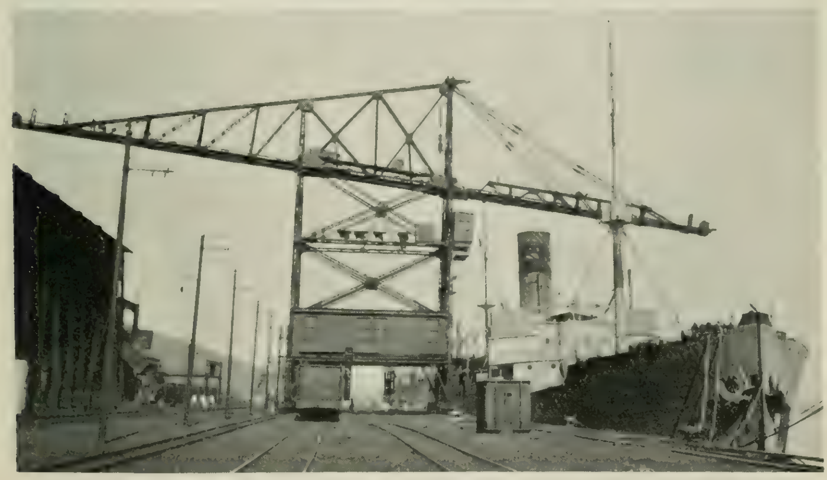


Fig. 3. *Grab Transporter, Hanyang Steel Works, China.*

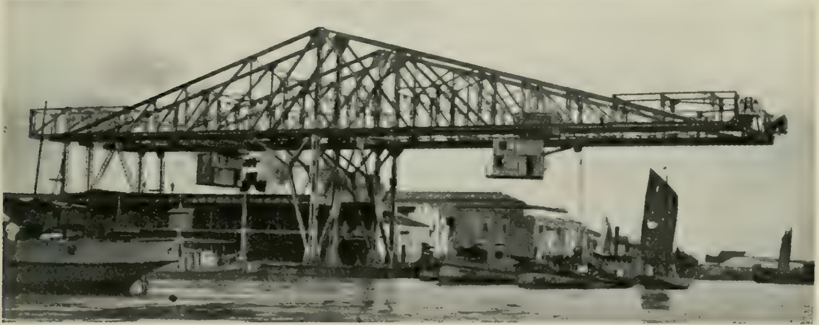


Plate 4.

MECHANICAL LOADING OF SHIPS.

Fig. 4. *Belt Conveyor Shipping Plant, Bilboa.*

Capacity 1,000 tons per hour. No Dock required.

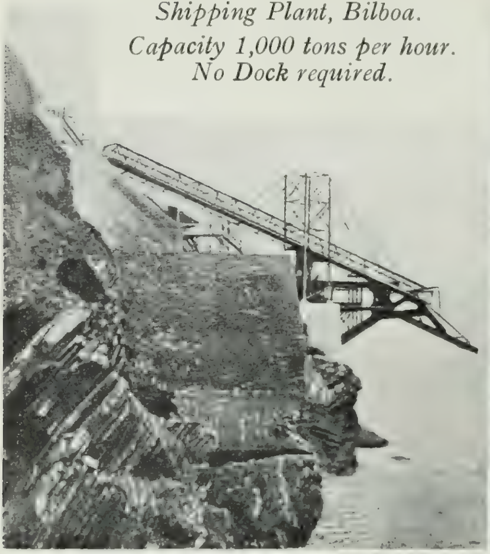


Fig. 5. *Bucket-Carriage, Sebabna Ropeway.*

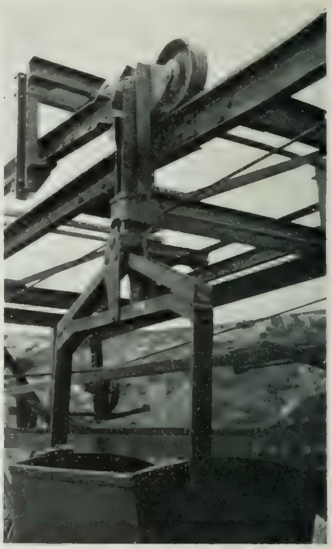


Fig. 6. *Shipping Plant, Sebabna Mines.*

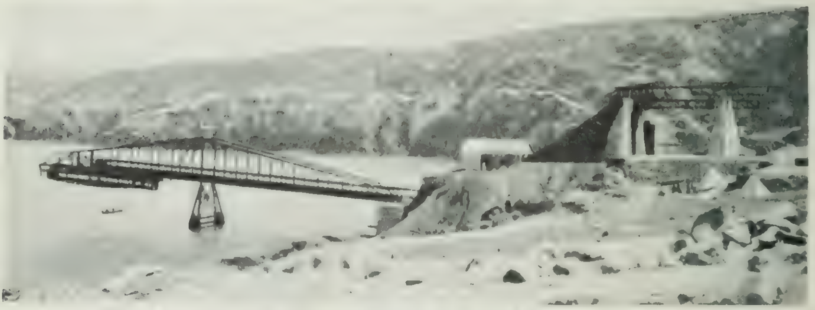
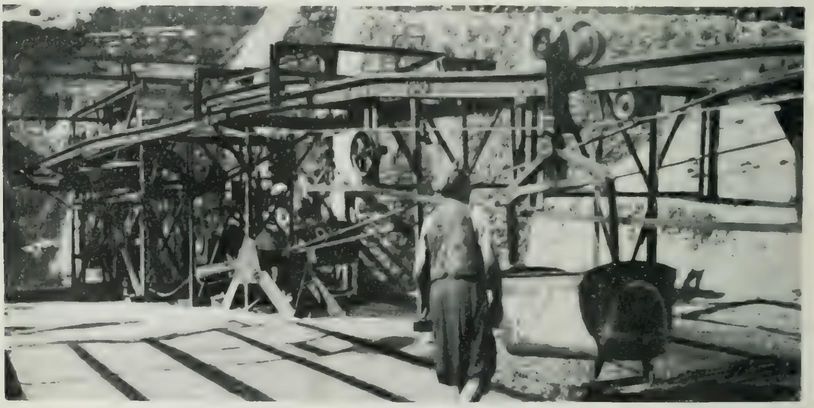


Fig. 7. *Loading Station at Mine, Sebabna Ropeway.*



Sebabna Plant.

Fig. 8. *Tension Station.*

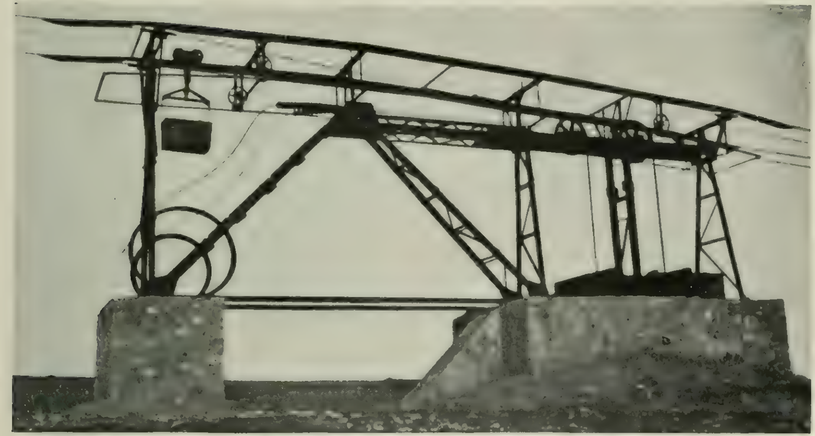


Fig. 9. *Details of Trestle.*

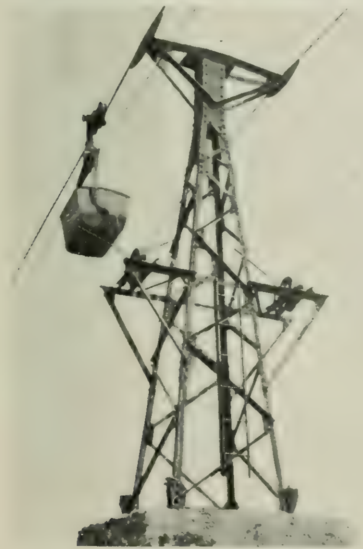


Fig. 10. *Bucket-Conveyor.*

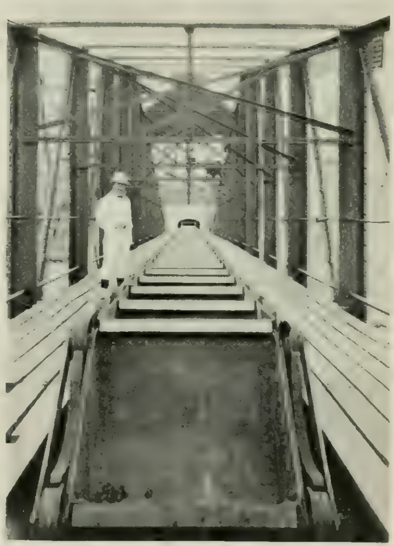


Fig. 11. *Ropeway Terminus and Storage Bunkers.*

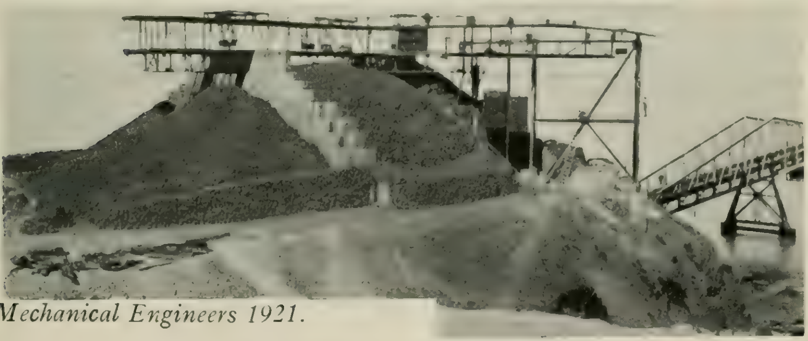


Fig. 12. *Bucket Runway connecting Bridge to Tunnel, Sebabna Mines.*

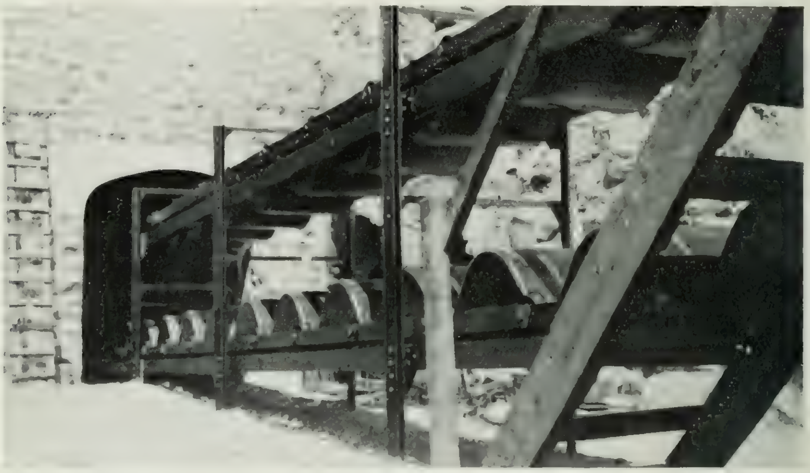


Fig. 15. *42-inch Movable Belt Shipping Plant.*
Loading capacity 500 tons per hour.

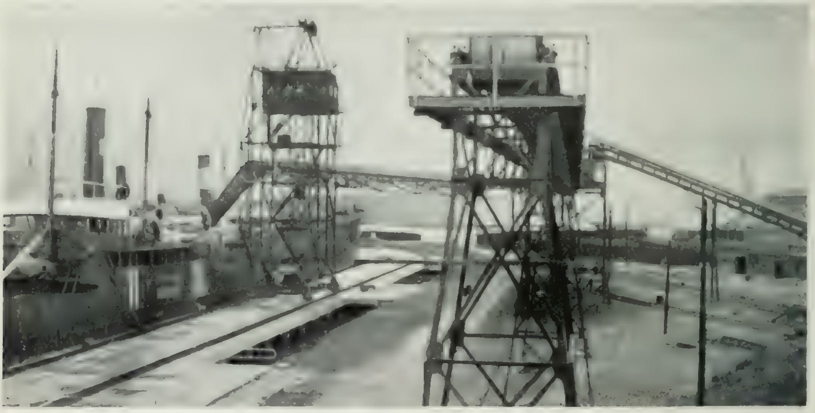


Fig. 16. *Dumper for Tipping 75-ton Wagons, Durban.*

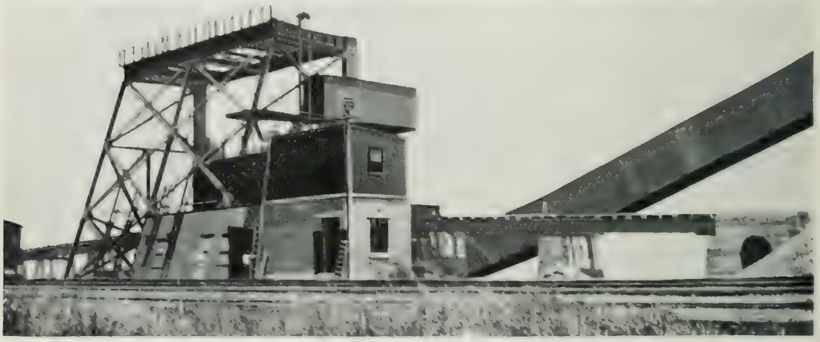


Fig. 17. *Grab Transporter, Han-Yeh-Ping.*

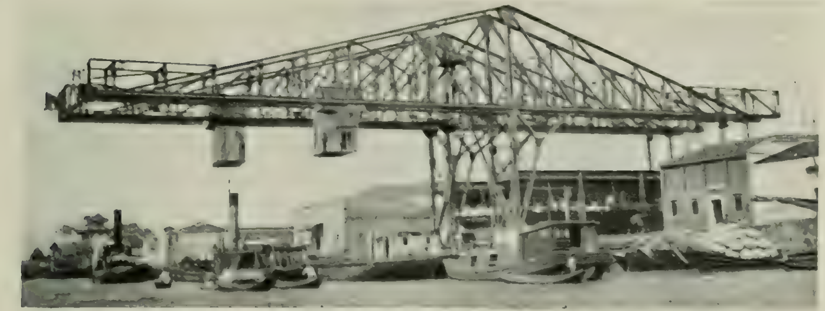


Fig. 18. *42-inch Fixed Belt Shipping Plant.*

Loading capacity
500 tons
per hour.

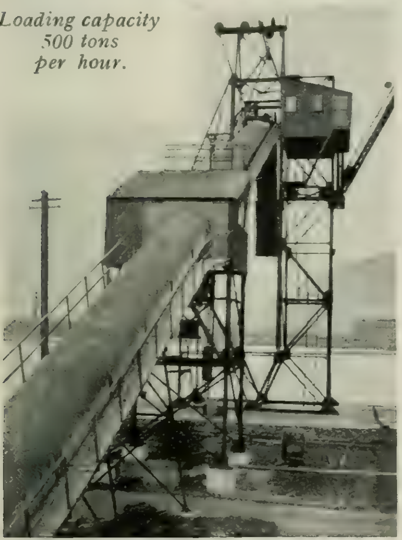


Fig. 19. *Bunkers of above Transporter.*

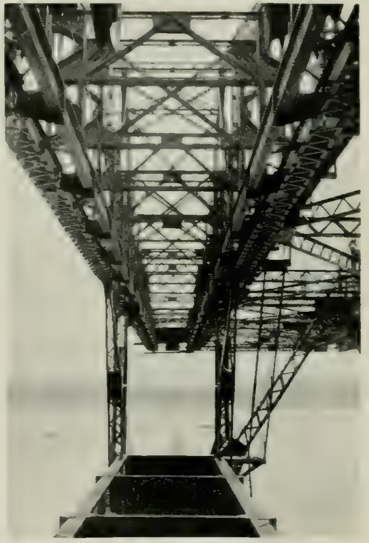
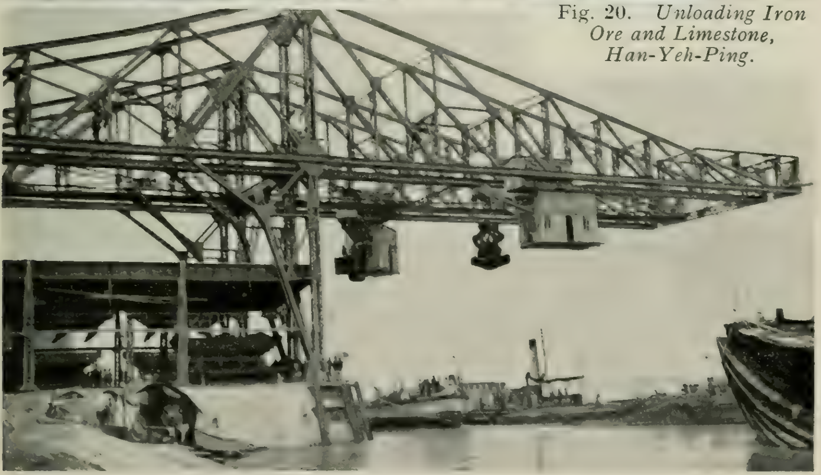


Fig. 20. *Unloading Iron Ore and Limestone, Han-Yeh-Ping.*



MECHANICAL LOADING OF SHIPS.

Grab Transporter, Han-Yeh-Ping.

Fig. 21. *General view of Structure.*

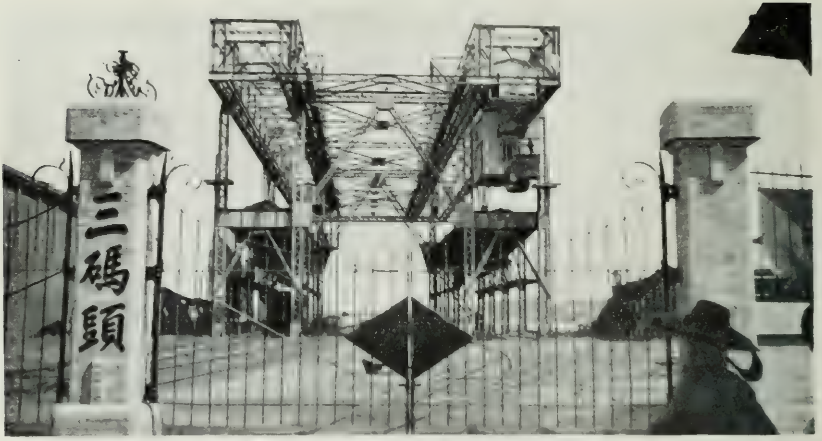


Fig. 22. *Wind Bracing between Bridges.*

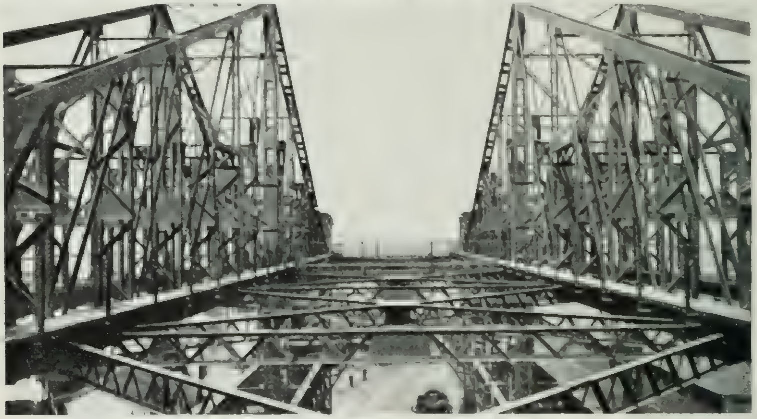
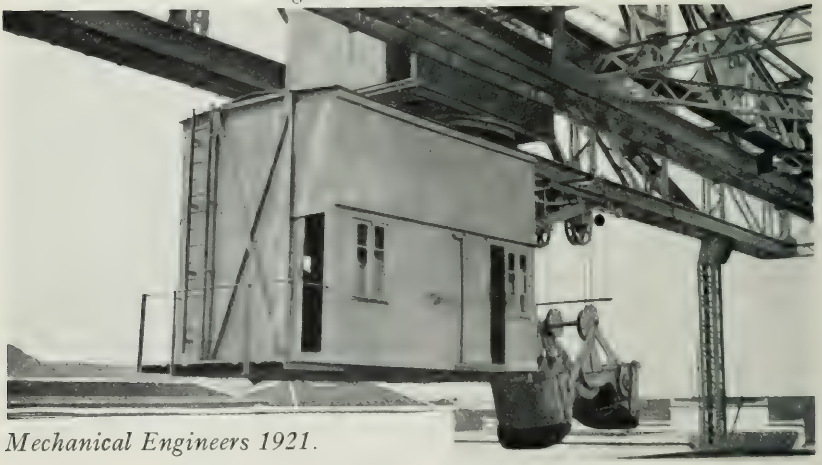
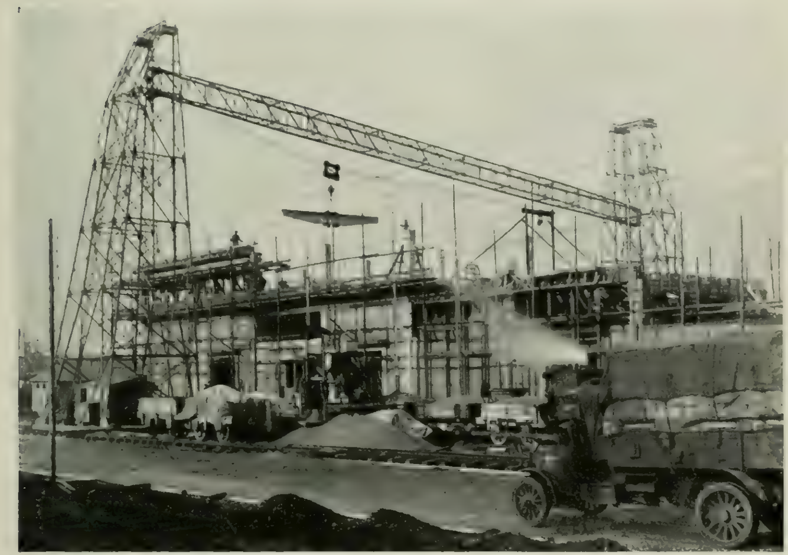


Fig. 23. *Grab and Traveller.*



(Mr. A. Binns' remarks.)

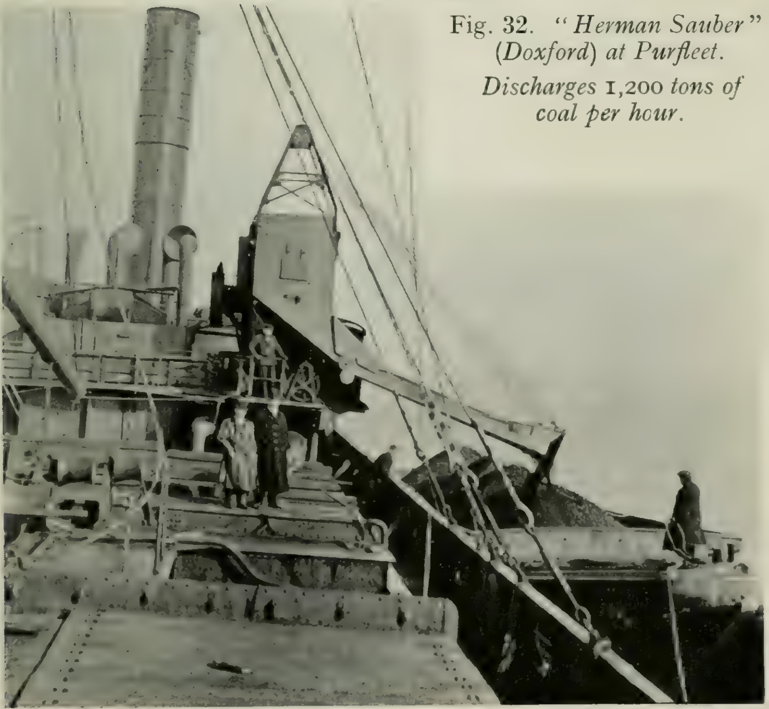
Fig. 31. *Long-Span Crane (Walker) Engaged on Dockyard Extensions.*



(Mr. J. H. Anderson's remarks.)

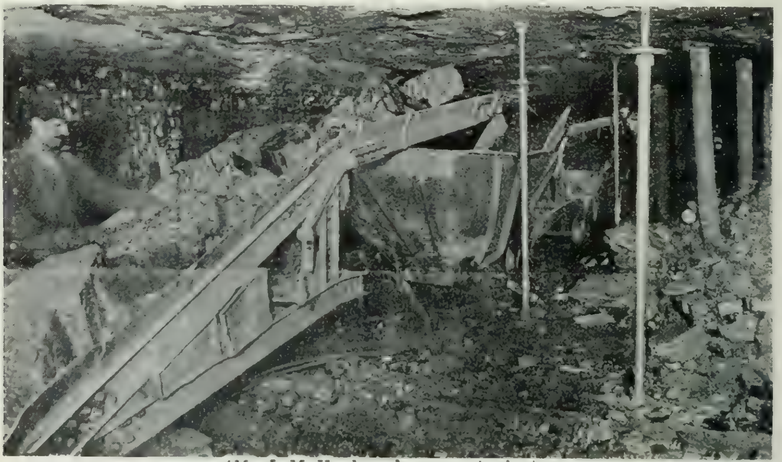
Fig. 32. *"Herman Sauber" (Doxford) at Purfleet.*

Discharges 1,200 tons of coal per hour.



(Mr. J. H. Anderson's remarks.)

Fig. 33. *Cutting and Loading Machine (Jeffrey), Coal being delivered to Storage Hopper.*



(Mr. J. M. Henderson's communication.)

Fig. 34. *Double-Inclined Gravitation Ropeway, Liverpool.*

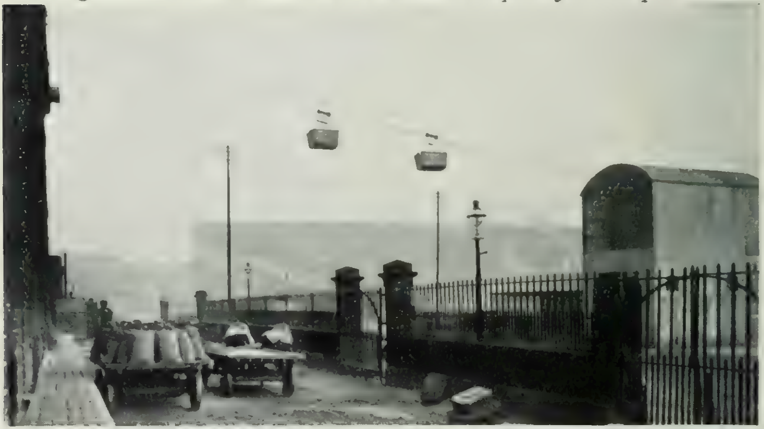
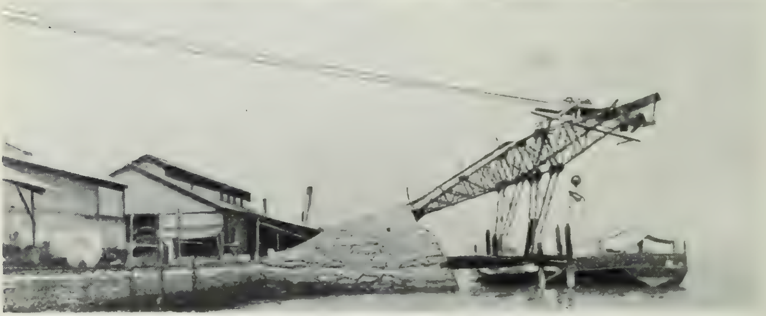


Fig. 35. *Aerial Cableway, Inclined Lower Support, Dock Works, Rio de Janeiro.*



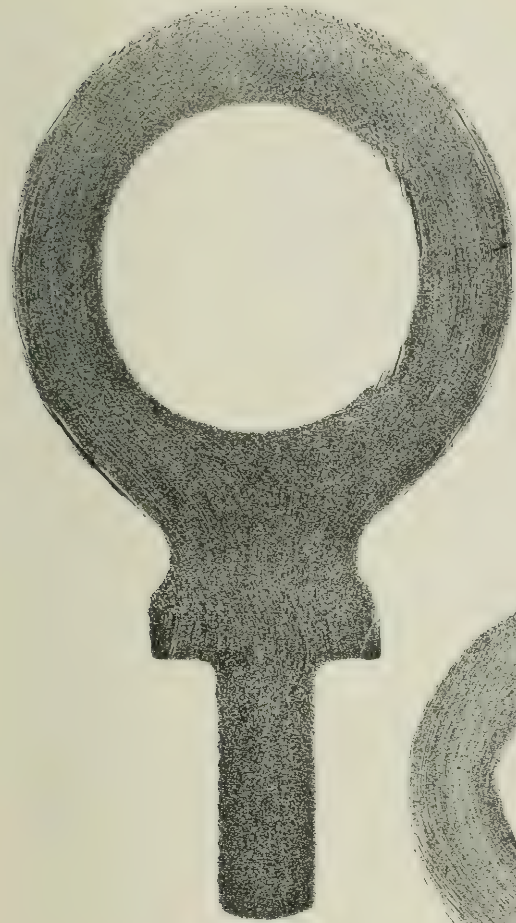


Fig. 1.

Macro-print
from
Outside Eyebolt No. 4.
($\frac{3}{4}$" *bolt with* 1$\frac{1}{2}$" *eye.*)

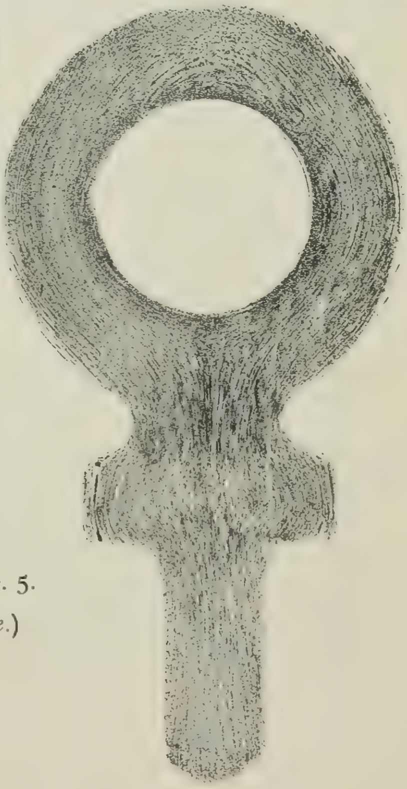
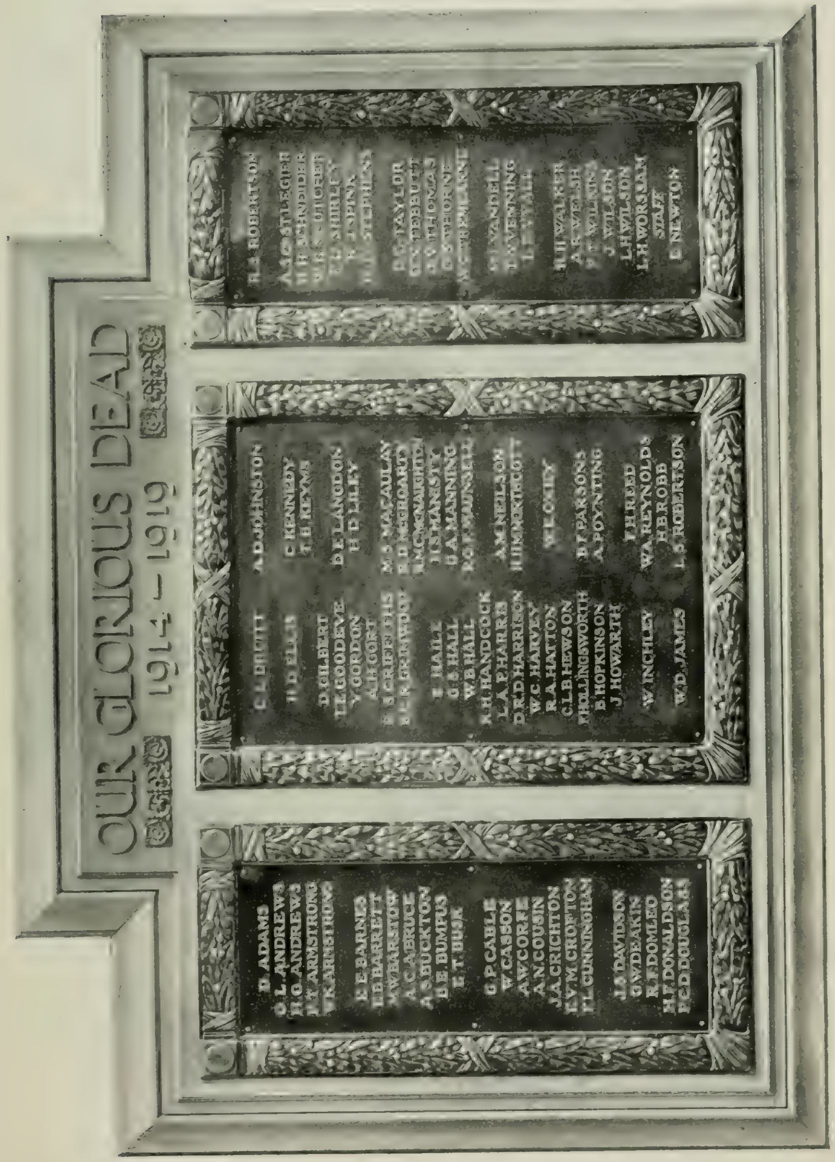


Fig. 2.

Macro-print
from
Outside Eyebolt No. 5.
($\frac{3}{4}$" *bolt with* 1" *eye.*)

Unveiled and Dedicated
17th February, 1921.



Mechanical Engineers 1921.

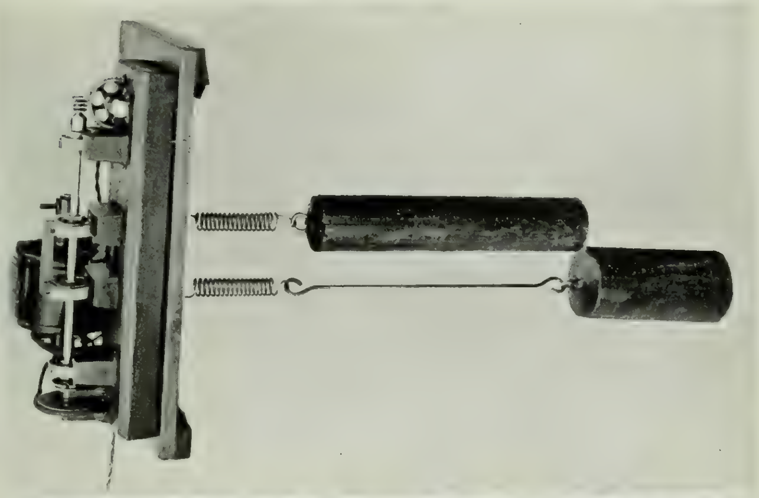


Fig. 5. *Machine for Specimens from Welds in $\frac{1}{2}$-inch material.*

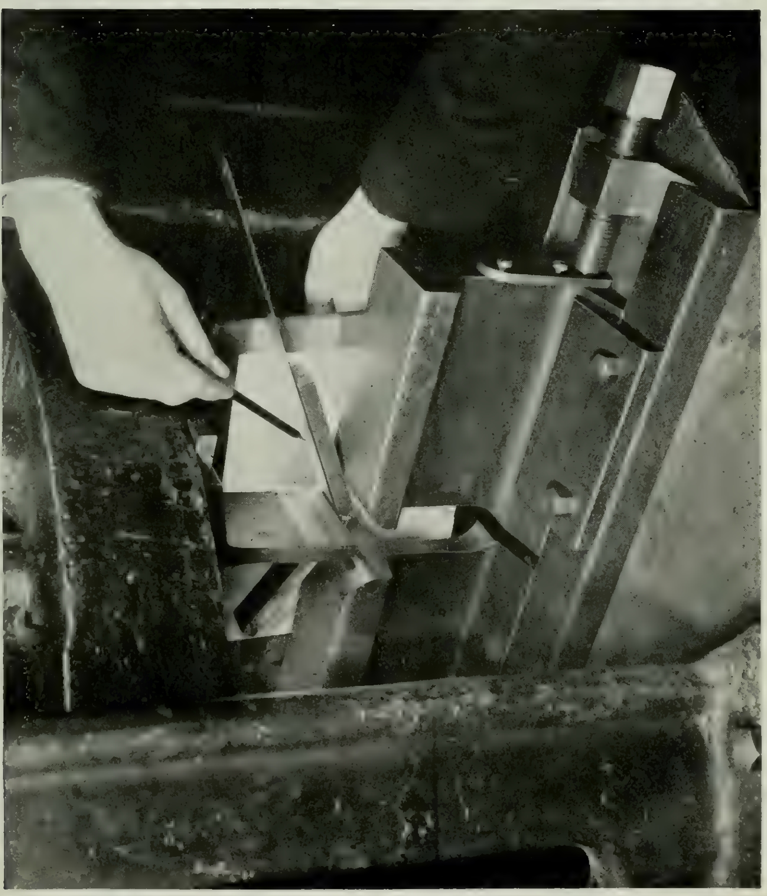


Fig. 3. *Bending Test Fixture at the Bureau of Standards, Washington.*

STANDARDIZATION OF TESTING WELDS.

(Dr. B. P. Haigh's remarks).

Fig. 8. *V Butt Weld, showing added metal and brittle structure produced by over heating. ×100 d.*

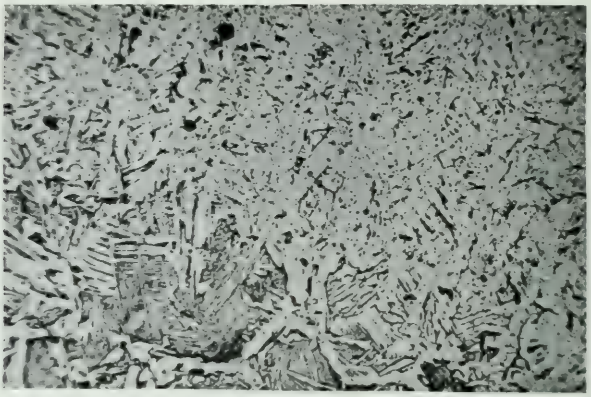


Fig. 9. *Above Butt Weld, Metal added in 3 distinct runs. ×2 d.*

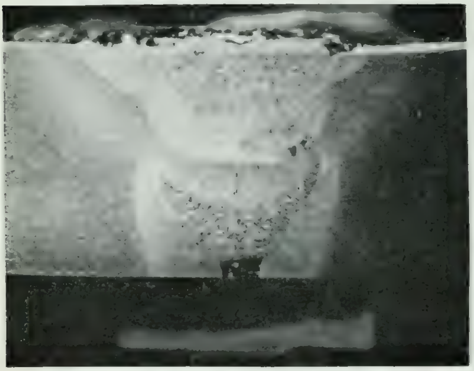


Fig. 10. *Face View of a Tensile Fracture, half appearing brittle and half not.*

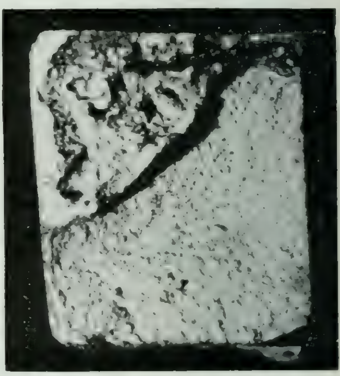


Fig. 11. *Tough part (Fig. 10.) showing Ferritic structure. ×500 d.*

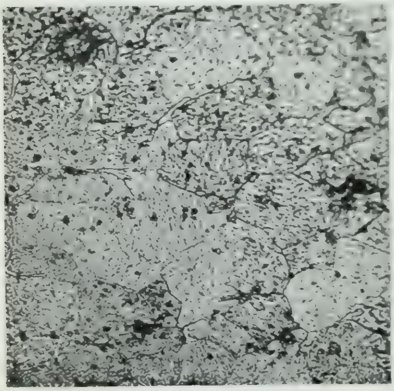
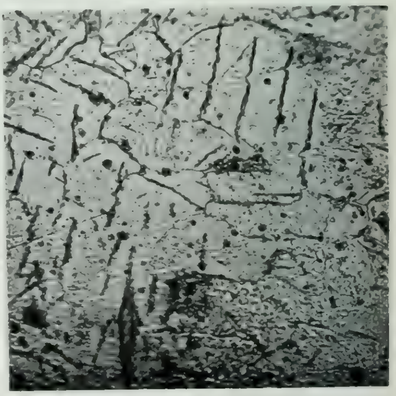


Fig. 12. *Brittle part showing laminated structure. ×500 d.*



(Mr. F. C. Hibberd's communication).

Fig. 13. *Mild Steel as Welded. ×450 d.*

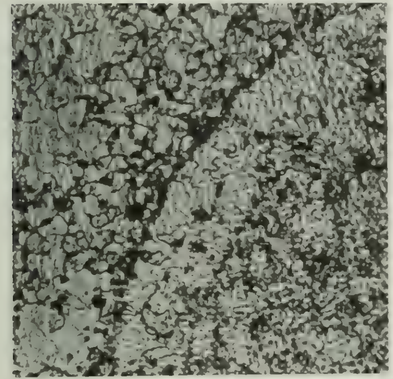


Fig. 14. *Mild Steel as Welded. 0·20% Carbon Steel. ×450 d.*

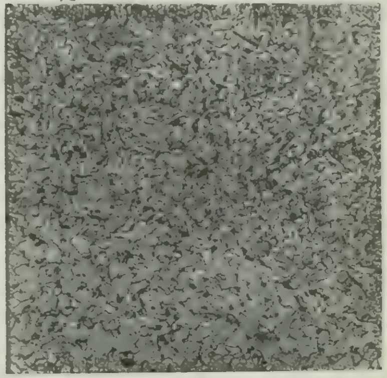


Fig. 15. *Mild Steel Annealed. ×450 d.*

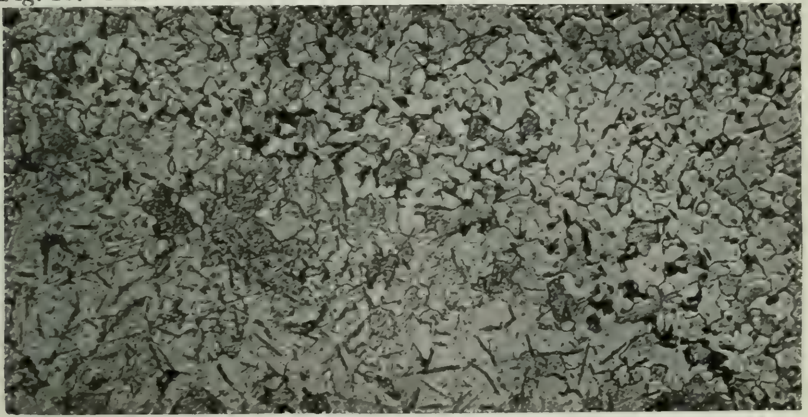


Fig. 16. *Mild Steel as Welded. ×450 d.*

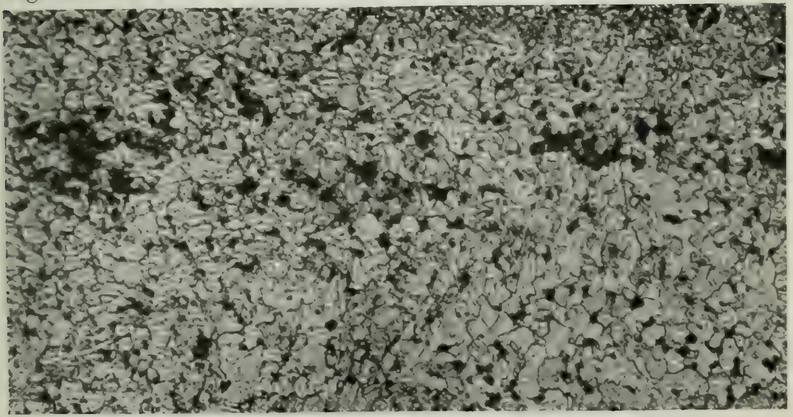


Fig. 8. *Stress in a Large Rectangular Block loaded over a small part of its upper surface.*

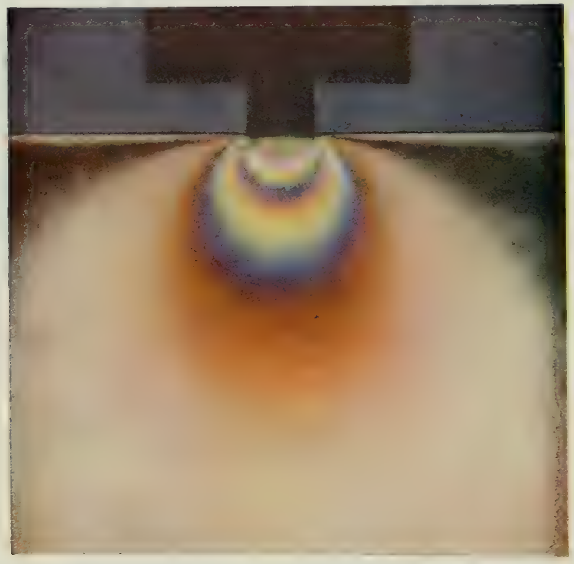


Fig. 11. *Stress in a Square Block loaded centrally over a part of its upper surface.*

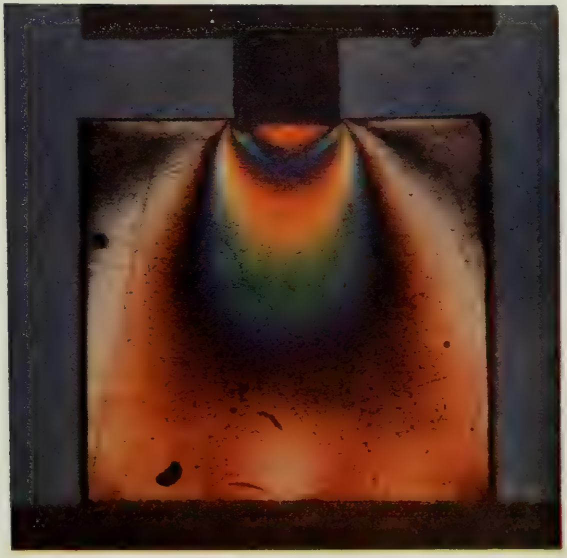


Fig. 25. *A Tension Test-piece gripped laterally by knife edges.*

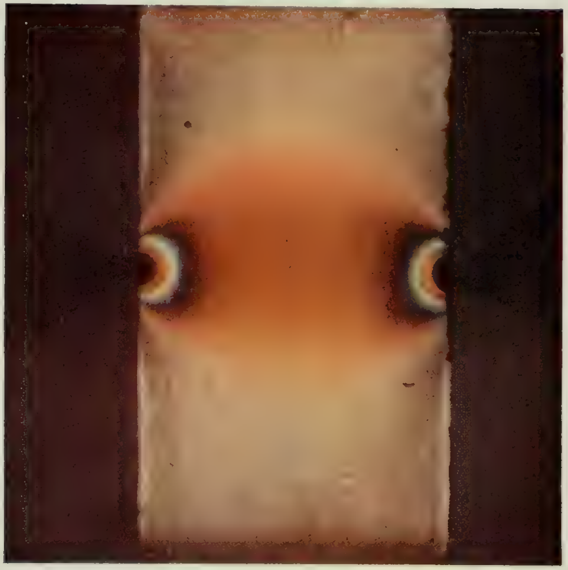
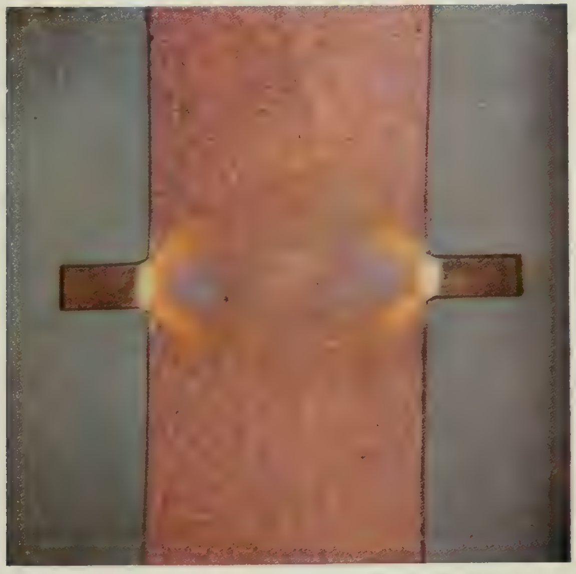


Fig. 29. *The Stress in a Flat Tension Test Specimen of the Contour used by Prof. Dalby.*



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